PALEOECOLOGY OF THE DELAWARE VALLEY REGION

PART II:

CRETACEOUS TO QUATERNARY

William B. Gallagher

Department of Geology, University of Pennsylvania
Philadelphia, Pennsylvania 19104

Abstract

In Part I of this work (*The Mosasaur*, Volume I, pp. 23-43; 1983), twenty-seven localities ranging in age from Cambrian to Jurassic were described. Part II presents detailed locality data for thirty-seven localities representing Cretaceous, Tertiary, and Quaternary time intervals. Introductory sections for each period relate general plate tectonic, oceanographic, and evolutionary developments to regional stratigraphy and paleoecology. Faunal lists are presented for each locality along with sedimentologic and paleoecologic interpretations of the specific sites. The Cretaceous sequence is interpreted as the result of eustatic sea-level change along a passive trailing continental margin, with centers of maximum sedimentation shifting in location through the Lower to Uppermost Cretaceous units. Changes in sea-level along with variations in depositional environment account for facies changes and differences in faunal content in individual units along strike. The Maestrichtian-Danian boundary is placed in the lower Hornerstown Formation on the basis of paleontologic evidence; this raises the possibility that a complete sequence of deposition across the Cretaceous-Tertiary boundary exists in New Jersey. After the terminal Cretaceous extinction event, diverse faunas gradually re-established themselves in this area in the Lower Tertiary. Again, eustatic sea-level change seemed to be the major control on deposition and fossil biota. In the Miocene, major oceanographic changes led to the inundation of large portions of the east coast of North America, and the resultant Chesapeake embayment extended into southern New Jersey. Quaternary deposits and their contained fossils reflect the relatively rapid effects of glacio-eustatic change. Holocene sea-level rise is exposing Flandrian peats and washing up Flandrian benthos along the New Jersey coast.

The Mosasaur, 2:9-43

Introduction

While Part I of this work concentrated on the response of the biota in the Delaware Valley region to one complete cycle of plate tectonic coalescence and initial rifting in a tectonically active setting, with its attendent changes in sedimentation and environment, Part II deals largely with the evolutionary paleoecology of a passive trailing continental margin during the continued opening of the North Atlantic Ocean. During this interval (Cretaceous to Quaternary), the primary influence on marine and continental-margin biota was largely eustatic change in sea-level along a tectonically quiescent coast, punctuated by relatively dramatic, geologically rapid events such as the Cretaceous-Tertiary extinction and the cyclical Pleistocene glaciations. Plate tectonic interactions, such as constriction of the Tethys Sea and the creation of the Isthmus of Panama, continued to exert influence on regional biota through their coupling to oceanographic and climatological processes, even though the areas of such interactions may have been far removed from the Delaware Valley.

As with Part I, it is hoped that this work will be of interest to advanced amateur paleontologists, students, teachers, and those researchers whose specialities lie within the area covered. Many of the localities listed herein are on private property; the usual precautions and courtesies should be observed when visiting these sites. While this may not be an exhaustive or definitive listing, and while many localities now available may disappear in the future, recording their existence and offering some detailed data on their paleontology for posterity seems a useful exercise, in the same way that paleontology itself is interesting for its record of previous existences.

Cretaceous

The beginning of the Cretaceous period brought renewed uplift along the Appalachian chain. Consequently the Delaware Valley was an area of non-deposition, or, if any sediments were laid down in the area at this time they were subsequently eroded away. To the southwest in Maryland, sediments carried down from the mountains by Lower Cretaceous rivers and streams were deposited as the sands and clays of the Potomac Group. In the Arundel Formation of this group a number of bones have been found indicating that the region was inhabited by a dinosaurian fauna related to that of the Upper Jurassic and Lower Cretaceous formations of the western United States. These fossils have been found in sedimentary iron deposits probably formed in swamps and marshes; the localities extend in a belt from Washington, D.C., to Baltimore, Md. The fauna includes a stegosaur (*Coelurus gracilus*), several sauropods (*Astrodon johnstoni*, *Pleurocoelus nanus*, *P. altus*; these may represent growth stages of a single species), an ornithopod (*Tenontosaurus* sp.), a carnosaur (*Dryptosaurus*? *medius*), as well as the crocodilian *Goniopholis affinis* (McLennan, 1973; Forster, 1984).

Associated with the reptile remains of the Potomac Group are plant fossils, including evidence of the most important evolutionary development in the Cretaceous--the relatively rapid adaptive radiation of the early flowering plants. The first angiosperms probably originated in seasonably arid environments, then underwent rapid diversification as they spread poleward and moved into new environments (Hickey & Doyle, 1977). Both pollen structure and leaf morphology become more complex during the course of the Cretaceous. By the Upper Cretaceous the angiosperms had become the dominant vegetation, largely supplanting previously abundant ferns, conifers, cycads, and gingkoes.

During Upper Cretaceous time the sea encroached upon and retreated from the land in a series of transgressive-regressive cycles that are recorded in the sands and clays of the Inner Coastal Plain of New Jersey and Delaware. The outcrop belt of these deposits strikes northeast to southwest from the Raritan Bay area, and the beds dip gently to the southeast. The oscillations in sea level that gave rise to these strata may be related to continuing sea-floor spreading activity opening up the Atlantic Ocean as the supercontinent of Pangaea continued to split apart; volumetric changes in ocean basins may be related to active and quiescent phases at mid-ocean ridges (Valentine & Moores, 1970). The latter part of the Cretaceous was a time of widespread submergence, and the sea life of this time was diverse and abundant. The dinosaurs and their relatives continued to rule the land, sea, and air, at least until the end of the Cretaceous when a worldwide extinction episode eliminated the great reptiles as well as many marine organisms. The cause of the terminal Mesozoic extinction has long been debated, and numerous theories have been proposed to account for it. An explanation currently in vogue is the hypothesis that a large extraterrestrial object struck the earth, creating a dust cloud so thick that sunlight was drastically reduced and photosynthesis was radically curtailed (Alvarez *et al.*, 1980). While this idea is supported by the presence of a widespread iridium-enriched layer at the Cretaceous-Tertiary stratigraphic boundary (Orth *et al.*, 1981; Alvarez *et al.*, 1984), it is not entirely in accord with paleontological data (Hickey, 1981; Hickey *et al.*, 1983; Archibald & Clemens, 1982; Officer & Drake, 1983). Most notably, terrestrial vegetation does not appear to have suffered the intensity of extinction rates that ravaged the dinosaurs and marine plankton.

At the end of the Cretaceous, a widespread regression of the sea appears to be coupled with a decrease in the equability of the Mesozoic climate. For much of the Mesozoic the earth seems to have enjoyed generally warm weather with a rather small range of temperature variation. This may have been caused by the ameliorative climatic influence of the extensive seas. Moreover, oceanic circulation patterns were different from marine circulation today. Large inland seas, such as the epeiric sea that covered much of western North America, along with the possibility of a far-ranging Tethyan equatorial current, moderated planetary weather and ocean temperatures. Increased plate teconic activity during the course of the late Cretaceous drained the epeiric seas and shut off warm Tethyan circulation as Africa, Arabia, Iran, and India began moving toward their present positions. Increased mountain-building and new oceanic circulation patterns caused a loss of ecospace, greater temperature fluctuations, and intense competition among organisms, resulting in extinctions.

It may be that no single cause will be sufficient to explain the terminal Mesozoic extinction. Perhaps it resulted from some combination of variation in the earth's or solar system's orbital parameters, an extraterrestrial impact, and plate tectonic processes. At any rate, it seems certain that deterioration of the late Mesozoic climate and regression of the seas can be safely correlated with the Cretaceous-Tertiary faunal changes.

28. Sayreville, Middlesex County, New Jersey

Lithology -- White, buff, orange, pink, and gray interbedded sands and clays.

Fossils -- Extensive sand and clay pits in this area exposed the Raritan Formation's colorful sequence of sands and clays. Some pits are now inactive and have been converted to other uses. The most common fossils found in the Raritan are plant remains. In the light gray clays there are abundant pieces of lignified wood that are remains of plants that grew along the ancient streams and estuaries. There are also fossil leaves in some of the clay layers; the best way to collect this material is to take out large blocks of clay, allow them to dry out for an extended period, then split them. This will ensure that the fragile leaves are not destroyed; splitting the clay while it is wet will probably result in breaking up the leaf material (Leo Hickey, personal communication). By the time the Raritan Formation was deposited in this area, angiosperm diversification was proceeding at a rapid rate; this evolutionary radiation may have had drastic consequences for some dinosaur groups. The Brachiosauridae and Stegosauria, both herbivorous groups, disappeared in the Lower Cretaceous when the angiosperms were beginning their dominance of the flora; the Ankylosauria, Ceratopsia, and Hadrosauridae appeared around the time of the major angiosperm radiation. In the Lower Cretaceous, the basal Potomac Group (Patuxent Formation) has yielded monosulcate pollen and simple entire-margined leaves of the first angiosperms (Hickey & Doyle, 1977); as one goes upward in the Potomac section, the number of different kinds of leaves increases. Leaf-forms, at first with disorganized venation, entire margins, and poor differentiation between petiole and leaf-blade, become diverse, more regular in venation, and more lobed. Increases in diversity and complexity of pollen forms in the Atlantic Coastal Plain Cretaceous deposits parallel diversification in leaf shapes and lend credence to the concept of a major evolutionary radiation. The incrementally greater complexity of the pollen's exine was probably due to the importance of plant-animal coevolution, in particular the influence of pollinating insects (Doyle & Hickey, 1976). By Raritan time, up to 70% of the plants were angiosperms. Some of the beds in the Lower Raritan may be Lower Cretaceous (Potomac) in age, on the basis of floral biostratigraphic evidence found in the Sayreville pits (Leo Hickey, personal communication). Indeed, Owens & Sohl (1969) have stated that south of Trenton the Raritan Formation sediments are indistinguishable from the Potomac deposits, and recently Jordan (1983) has suggested limiting the use of the term "Raritan Formation" strictly to describe the deposits in the type area around Raritan Bay.

Most of the Raritan beds appear to be of subaerial deltaic origin, as indicated by the large amount of lignitic plant fragments and by sedimentary features such as crossbedded sands. In one stratum, however, a marine fauna has been found. The Woodbridge clay member of the Raritan contains sideritic concretions with enclosed fossils, mostly mollusks, in the Sayreville pits. At first, the sparse fauna was interpreted as a brackish water assemblage; as more fossils were found, more salt-water species were recognized (Richards, 1943). Owens & Sohl believe that the clay "is a mangrove swamp deposit formed near the delta edge where occasional storms swept marine organisms into this environment" (1969, p. 255). The Woodbridge clay does contain abundant lignitized wood. Regardless of whether it was deposited in a marine, estuarine, or marginal-marine environment, this bed seems to indicate the first pulse of marine encroachment in the Upper Cretaceous cycle of transgression and regression of the sea.

The mollusk fossils of the Woodbridge clay are enclosed in concretions, poorly preserved, and rarely found. A list of genera (derived from Richards, 1943) contains names of forms familiar to students of the Upper Cretaceous in New Jersey: *Corbula, Cardium, Pinna, Exogyra, Anomia, Inoceramus, Plicatula, Anchura, Avellana, Gyrodes,* and *Turritella.* These pelecypods and gastropods represent the first occurrence of a typical invertebrate fauna which reoccurs in succeeding marine beds.

Berry (1911) recognized 160 to 170 species of plants in the Raritan Formation. Aside from some ferns and a few dozen conifers, most of them were dicotyledonous angiosperms. Berry listed members of the figs, magnolias, tulip trees, and laurels as represented in the flora. However, Doyle & Hickey (1976) have cautioned against the premature use of modern names in taxonomic placement. Palynological evidence shows that the Normapolles complex first appears in the Raritan (zone IV of Doyle & Hickey); this type of pollen is interpreted as "Amentiferae" in origin (Hickey & Doyle, 1977). The Amentiferae is a synthetic taxon composed of many small orders of primitive wind-pollinated trees, some of them closely related to the modern sycamore.

Vertebrates are represented by large dinosaur footprints found in the Woodbridge clay (Wolfe, 1977) at Woodbridge, N.J., by a possible carnosaur bone from the Raritan of Roebling, N.J. (Baird, personal communication), and by a plesiosaur bone (*Taphrosaurus lockwoodi*) probably from Sayreville (Lewis & Kummel, 1940; Miller, 1955; Parris, 1974).

A most unusual find from this site was reported by Baird (1966). A piece of amber containing several fossil insects was collected by Gerald Case from the Sayreville pit. Upon study by entomologists they were identified as midges belonging to the families Chironomidae and Ceratopogonidae.

Age -- Raritan Formation, early Upper Cretaceous (Cenomanian).

29. Cliffwood Beach, Monmouth County, New Jersey

Lithology -- Alternating layers of dark lignitic clay and light colored sand.

Fossils -- As in the Raritan Formation, plant remains are very common. Fossil leaves, bits of stems and twigs, and entire tree trunks preserved upright in life position have been found at this locality. Perhaps the most famous fossils found here are pieces of amber; one such piece has a Cretaceous ant preserved within it, a rare and unusual find. The amber is the congealed and hardened sap of trees, probably angiosperms.

At the base of the exposure a layer of siderite nodules preserves a fauna of mollusks and *Callianassa* claws. Sideritic concretions along the beach may contain these fossils. The remains are primarily those of marine forms, so once again the sea encroached upon the terrestrial environment. The sandy layers are crossbedded and were probably deposited in streams or rivers meandering across a floodplain (Jordan, 1983).

It should be noted that the status of this locality is somewhat in doubt. There are plans to create an artificial sand slope over the cliff exposure in order to control erosion.

Age -- Magothy Formation, Upper Cretaceous (Coniacian-Santonian).

30. Oschwald's Pits, Cliffwood, Monmouth County, New Jersey

Lithology -- Glauconitic clay, black weathering to brown, with limonite and siderite concretions, overlying Magothy sand and clay.

Fossils -- In some sections of the pit the lignitic Magothy beds with their abundant plant fragments can be observed; above them and dipping to the southeast is the Merchantville Formation. This massively-bedded black clay contains glauconite, a complex iron potassium silicate that is only deposited under marine conditions. In purer forms, it is commonly known as greensand and it gives its characteristic dark green color to many of the marls that were mined during the nineteenth century for fertilizer. The old marl pits produced an abundant array of fossil marine life, and it is in the glauconitic beds of New Jersey that the best fossil faunas are found. At these pits, however, the glauconitic clay was mined for brickmaking.

The fossils are generally found as individual steinkerns or as casts and/or molds in siderite concretions. Siderite is dark red to brown ferrous carbonate; streams and rivers brought iron down to the sea, and decaying organic matter probably provided the right pH conditions for the precipitation of the iron with carbonate from the seawater. Thus the future fossil acted as a "seed" around which the concretion grew. Oxidation of siderite produces limonite.

The most abundant group represented at this locality is the mollusks. These include:

Pelecypoda

Panopea decisa Conrad
Glycimeris mortoni (Conrad)
Cucullaea antrosa Morton
C. neglecta Gabb
Cardium tenuistriatum Whitfield

Gastropoda

Lunatia halli Gabb
Gyrodes petrosus (Morton)
Turritella merchantvillensis Weller
Anchura rostrata (Gabb)
Avellana bullata (Morton)
Turbinella intermedia Weller

Cephalopoda

Menabites delawarensis (Morton)
Placenticeras placenta (DeKay)

P. placenta is usually found with sections of the shell broken off along the septa and complex suture lines, but entire specimens of this ammonite up to 18 inches in diameter are known from this locality. Other groups present at this site are the malacostracans (*Callianassa*) and annelids (*Hamulus* and *Longitubus* tubes).

Age -- Magothy Formation (Coniacian-Santonian) and Merchantville Formation, Matawan Group, Upper Cretaceous (Campanian).

31. Bordentown, Burlington County, New Jersey

Lithology -- Weathered brown clay with brown limonite and siderite concretions, overlain by dark greenish black clay with marcasite concretions.

Fossils -- During construction for the Route 295 overpass and exit onto Route 130, the contact between the Merchantville Formation and the overlying Woodbury Formation was superbly exposed. Many excellent specimens were available from the Merchantville, but above the abrupt contact between the two formations the Woodbury was devoid of fossils. The excavation has been sodded over, but some limited exposure may be seen in the gullied areas along Route 130 near Black Creek. Years ago Merchantville fossils were obtained from the old abandoned Church Pit two miles southwest of Bordentown (Richards, 1958). At the road cut, the following fossils were found:

Annelida

Hamulus falcatus (Conrad)

Arthropoda

Callianassa mortoni Pilsbry

Cephalopoda

Menabites delawarensis (Morton)
Placenticeras placenta (DeKay)
Baculites ovatus Say

Gastropoda

Turritella merchantvillensis Weller
Gyrodes petrosus (Morton)
Anchura rostrata (Gabb)
Lunatia halli Gabb

Pelecypoda

Cucullaea antrosa Morton
C. neglecta Gabb
Glycimeris mortoni (Conrad)
Cardium tenuistriatum Whitfield
Pecten (Neithea) quinquecostata Sowerby
Trigonarca cuneiformis Conrad
Anomia argentaria Morton
Corbula sp.
Agerostrea sp.

Again, this is a marine fauna of the sort typically associated with the glauconite beds. There are pieces of lignified wood present, probably floated in from nearby land. Owens & Sohl (1969) imply that the sea deepened during the Merchantville, with delta bottomset beds represented at the bottom of the formation in the Raritan Bay area, then more massively-bedded inner and outer shelf deposits higher up in the section and to the south.

Age -- Merchantville and Woodbury Formations, Matawan Group, Upper Cretaceous (Campanian).

32. Industrial Park, Maple Shade, Burlington County, New Jersey

Lithology -- Massive black micaceous clay weathering to brown, with siderite concretions and marcasite nodules.

Fossils -- Years ago the Industrial Park on Route 73 near the intersection with Camden Avenue was the site of the old Graham Brickyard. At that time the Merchantville Formation was extensively exposed here, and various excavations in the area (notably for the Moorestown Mall and for Interstate 295) also revealed this fossiliferous stratum. Today, however, the exposures are reduced to a small sloping area alongside Kaplan Industries and a small railroad embankment in the Industrial Park. Large and varied collections of marine fossils were obtained here, but limited exposure yields scarce pickings at the present; future excavations may change that. Typical marine forms found here include:

Porifera

Cliona cretacica Fenton & Fenton

Coelenterata

Astrangia cretacea (Bölsche)

Bryozoa

Unidentified colonies on shells

Annelida

Hamulus falcatus (Conrad)
H. squamosus Gabb
Longitubus lineatus (Weller)
Diploconcha cretacea Conrad

Echinodemata

Pieces of ambulacral area

Crustacea

Callianassa mortoni Pilsbry
Hoploparia gladiator Pilsbry
H. gabbi (Pilsbry)

Pelecypoda

Cucullaea antrosa Morton
C. neglecta Gabb
Glycymeris mortoni (Conrad)
Pinna laqueata Conrad
Pecten (Neithea) quinquecostata Sowerby
Trigonia mortoni Whitfield
Anomia argentaria Morton
Inoceramus proximus Tuomey
Pholadomya occidentalus Morton
Trigonarca cuneiformis Conrad
Cardium tenuistriatum Whitfield
Panopea decisa Conrad
Liopistha protexta (Conrad)
Ostrea cf. *mesenterica* Morton
Exogyra sp.

Gastropoda

Turritella merchantvillensis Weller
T. encrinoides Morton
Lunatia halli Gabb
Gyrodes petrosus (Morton)
Xenophora leprosa (Morton)
Anchura rostrata (Gabb)
Rostellites nasutus (Gabb)
Turbinella intermedia Weller
Cerithium pilsbryi Whitfield
Volutoderma biplicata (Gabb)
Volutomorpha conradi (Gabb)

Cephalopoda

Baculites ovatus Say
Scaphites hippocrepis (DeKay)
Placenticeras placenta (DeKay)
Menabites delawarensis (Morton)

Chondrichthyes

Scapanorhynchus texanus (Roemer)
Lamnoid shark teeth
Batoid (ray) vertebrae
Ischyrhiza mira Leidy

Reptilia

Bothremys cooki Leidy
Clidastes sp.?
Mosasaurus sp.
Unidentified crocodile remains
Hadrosaur indet.--large metatarsal

Weller (1907) characterized the Upper Cretaceous New Jersey faunas as being of two types: a *Cucullaea* fauna and a *Lucina* fauna. The two assemblages roughly alternate in occurrence through succeeding beds of the Matawan and Monmouth Groups. Weller believed that the *Cucullaea* suite represented deeper water conditions, while the *Lucina* assemblage indicated shallow water environments. The *Cucullaea* fauna is associated with glauconite beds and has a greater diversity and abundance than the *Lucina* association, which is usually found in clays or clayey sands. The two groups probably lived in their respective zones contemporaneously, migrating back and forth as sea level transgressed to the northwest or regressed to the southeast. The Merchantville Formation contains the first expression of the *Cucullaea* fauna that lived in inner to outer shelf environments: some of the genera present (such as *Turritella, Xenophora, Cerithium,* and *Pinna*) are today more typical of southerly warmer waters.

Age -- Merchantville Formation, Matawan Group, Upper Cretaceous (Campanian).

33. Bellmawr, Camden County, New Jersey

Lithology -- Mixed spoil; primarily light grayish-brown to dark greenish-gray micaceous clay.

Fossils -- Spoil mounds on the property of the Bellmawr Landfill along Route 42 near Big Timber Creek contain a mixture of marine fossils. Two or possibly three formations are represented in the material in the heaps immediately behind the old rest area turn-off just south of the intersection with Route 295. Unfortunately the rest area and the landfill are now strictly off limits; the owners of the dump will not allow anyone on it. An extensive fauna is found here, particularly rich in sharks' teeth; these are usually bleached and weathered-looking.

Annelida

Hamulus falcatus (Conrad)

Crustacea

Hoploparia sp. claws

Pelecypoda

Panopea decisa Conrad
Cardium tenuistriatum Whitfield
Glycymeris mortoni (Conrad)
Legumen concentricum Conrad
Cymella bella Stephenson
Exogyra ponderosa Roemer
Gastrochaena whitfieldi Weller
Agerostrea sp.

Gastropoda

Turritella encrinoides Morton
Avellana bullata (Morton)

Cephalopoda

Placenticeras placenta (DeKay)
Scaphites hippocrepis (DeKay)

Chondrichthyes

Ischyrhiza mira Leidy
Ischyodus sp.
Squalicorax pristodontis (Agassiz)
Scapanorhynchus texanus (Roemer)
Odontaspis sp.
Shark vertebrae

Osteichthyes

Enchodus ferox Leidy
Anomoeodus phaseolus (Hay)

Reptilia

Crocodile scute
Mosasaur indet.--vertebra

Some of the spoil piles are largely composed of a darker clay with a fauna of very fragile original shell material; this original preservation is typical of the Woodbury Formation. Many of the invertebrates are preserved as siderite steinkerns or in siderite concretions; this is a mode of preservation more characteristic of the Merchantville Formation. *Placenticeras placenta* occurs here both as a Merchantville-type steinkern and as a delicate original mother-of-pearl shell. Moreover, the presence of *Exogyra ponderosa* and the composition of the vertebrate fauna (see Lauginiger, 1984) suggest an admixture of Marshalltown material. About one-quarter of a mile south, excavations for Route 55 between Route 42 and the Deptford Mall have exposed the disconformable relationship between the top of the Marshalltown and the bottom of the Wenonah sand. Associated spoil piles yield a shark tooth fauna similar to the teeth from the Marshalltown of Delaware.

Age -- Merchantville, Woodbury, and Marshalltown Formations, Matawan Group, Upper Cretaceous (Campanian).

34. Barclay Farms, Cherry Hill, Camden County, New Jersey

Lithology -- Massive black micaceous clay weathering to chocolate brown color.

Fossils -- There are exposures of Woodbury clay in the banks of a small stream that flows south from a culvert under Cooperskill Avenue in the Barclay Farms section of Cherry Hill. In the point bar gravels there are fragments of snails (*Turritella, Anchura, Lunatia*), small clams, pieces of ammonite steinkerns (*Placenticeras*), worm tubes (*Hamulus* sp.), and lamnoid shark teeth. In the clay itself, however, there are no fossils; the material in the point bars appears to be a Merchantville fauna. Apparently the highly broken and eroded "float" is derived from the underground drainage beyond the culvert. This problem of fossil transport is common in stream and spoil pile fossil localities.

Age -- Matawan Group, Upper Cretaceous (Campanian).

35. Haddonfield, Camden County, New Jersey

Lithology -- Massive black micaceous clay weathering to chocolate brown color.

Fossils -- Banks along a small tributary to the Cooper River near Maple Avenue expose the Woodbury Clay. The fossils in this clay are all original shell material; great care must be taken to ensure that fragile specimens are not destroyed in the process of removal. The preferred method of collection is to remove a block, allow it to dry out, then carefully extricate the fossils and coat them with shellac or a plastic preservative.

The marine fauna at this site is a typical *Lucina* assemblage. The lack of glauconite probably indicates near-shore conditions; the clay was deposited in a low-energy environment, either below wavebase near the beach or else in lagoons. Richards (1956) reports the following species from this locality:

Coelenterata

Trochocyathus woolmani Vaughan

Pelecypoda

Gervilliopsis ensiformis (Conrad)
Trigonia eufaulensis Gabb
Cyrimeria depressa Conrad
Cardium ripleyanum Conrad
Vetericardia crenilata (Conrad)
Linearia metastriata Conrad
Corbula crassiplica Gabb

Scaphopoda

Dentalium subarcuatum Conrad

Trigonia, Cyprimeria, Cardium, and *Corbula* were infaunal burrowers, as was the scaphopod or "tusk shell" *Dentalium*. The solitary coral *Trochocyathus* was epifaunal, living on the surface of the sea bottom.

It was along the banks of this stream that the first reasonably complete dinosaur skeleton in North America was discovered. In the 1830s, workers digging in a marl pit on the Hopkins farm uncovered some large bones. Twenty years later John E. Hopkins related this occurrence to W. Parker Foulke, an amateur paleontologist and a member of the Academy of Natural Sciences of Philadelphia. With Hopkins' cooperation, Foulke relocated the site of the old pit, which by then was filled in and overgrown. Assembling a company of experienced marl diggers, Hopkins and Foulke excavated the old pit and after much work "came upon a pile of bones" between nine and ten feet below the surface (Leidy, 1858). Foulke took these remains to Dr. Joseph Leidy at the Academy, who formally described and named them as *Hadrosaurus foulkii*. This was an ornithopod or "duck-billed" dinosaur of a type synonymous with the western form known as *Kritosaurus* (Baird & Horner, 1977). Horner (1979) has noted that hadrosaur remains are the most common dinosaur fossils found in marine deposits, and Gallagher (1982) has proposed that hadrosaurs ranged into coastal ecosystems to feed on tough-stemmed estuarine vegetation.

It should be noted that the famous American vertebrate paleontologist Edward Drinker Cope lived in Haddonfield from 1868 to 1876, during which time he discovered additional dinosaur bones in the marl pits of southern New Jersey. Osborn (1931) called this time Cope's happiest and most productive period.

Age -- Woodbury Formation, Matawan Group, Upper Cretaceous (Campanian).

36. Oak Valley, Gloucester County, New Jersey

Lithology -- Dark green micaceous clay.

Fossils -- Above the Woodbury Clay lies a bed of white or buff-colored quartz sand called the Englishtown Sand. This stratum was probably deposited in deltaic and beach environments; it is cross-bedded in places, devoid of fossils in its outcrop belt, and represents a regression of the Cretaceous sea. Stratigraphically above the Englishtown is a layer of glauconitic clay with another marine fauna, indicating that once again the ocean was transgressing. Species found here include:

Porifera

Cliona cretacica Fenton & Fenton

Pelecypoda

Pecten (Neithea) quinquecostata Sowerby
Paranomia scabra Morton
Pycnodonte (Gryphaea) convexa (Say)
Exogyra ponderosa Roemer

Other outcrops of the Marshalltown are reported by Richards (1956) at Fellowship (now Mount Laurel), Burlington County; Cherry Hill, Camden County; and at Swedesboro, Gloucester County. The Marshalltown is glauconitic enough to have been mined for fertilizer when greensand marls were

still utilized for farming. Glauconite is a hydrous potassium aluminum silicate structurally related to the micas. It generally forms only under marine conditions, probably at depths less than 600 feet under water in restricted reducing environments. While some authorities believe that glauconite forms authigenically from clay minerals such as montmorillonite, there is much evidence to suggest that it is actually an organic byproduct. Boyer *et al.* (1974) assert that Marshalltown glauconite contains large proportions of fecal pellets; the accordion-shaped glauconite grains are very similar to the fecal pellets of modern mollusks. Botryoidal grains may be foraminifera tests or more likely the agglomeration of smaller pellets.

Pecten belongs to a group of highly mobile pelecypods that can swim by clapping their valves together and expelling water; these scallop-types have well-developed ribs to strengthen their valves, and a series of eyes located around the margin of the shell. *Paranomia* is a spiny byssate form that attached itself to the sea-bottom by means of strong threads, much like a modern mussel. *Exogyra* and *Pycnodonte* were sessile benthonic oysters. The various species of *Exogyra* have been used to zone the Upper Cretaceous deposits of the Atlantic and Gulf Coastal Plains; *E. ponderosa* is used to indicate the Marshalltown Formation and Upper Campanian equivalents farther south (Richards, 1958).

Age -- Marshalltown Formation, Matawan Group, Upper Cretaceous (Campanian).

37. Irish Hill, Runnemede, Camden County, New Jersey

Lithology -- Fine-grained micaceous quartz sand, white to orange-red, with conspicuous layers of limonite, grading upward into glauconitic pebbly sand.

Fossils -- Although the exposure between Route 41 and the New Jersey Turnpike is now much reduced from its former extent, the Wenonah Formation is still observable here. In the gullied areas, fossil burrows are etched out in relief on the weathered surfaces; generally vertical in orientation, they are orange-brown in color and exhibit a nodular surface. Although previously thought to be the burrows of a large annelid and described as such under the name *Halyminites major* Lesquereux, these tubes are now believed to be the burrows of decapod crustaceans and have been reassigned to the ichnospecies *Ophiomorpha nodosa* Lundgren. They are usually interpreted as trace fossils produced by the ghost-shrimp *Callianassa*, whose claws are frequently found in other formations of the New Jersey Upper Cretaceous. The skeleton is not frequently fossilized because of its low mineral content, but ghost-shrimp claws are calcified and hence more easily preserved (Thompson, 1982). The burrows are byproducts of *Callianassa*'s ability to move sediment; Thayer (1983) cites data attesting to the bioturbation effectiveness of the Thalassinidae (mud shrimps). Today the Callianassid shrimps are found from the intertidal zone to about 100 feet underwater, usually in sandy mud where they excavate extensive burrows, from Nova Scotia to the Caribbean.

The upper glauconitic and pebbly layer at this site is probably the Mount Laurel Formation. Owens & Sohl (1969) report the presence of the fossiliferous Marshalltown Formation at the base of the exposure here, but that stratum is not apparent at the present.

Age -- Wenonah Formation, Matawan Group, Upper Cretaceous (Campanian).

38. Chesapeake and Delaware Canal, Newcastle County, Delaware

Lithology -- Alternating beds of sand and glauconitic clay.

Fossils -- The various exposures and spoil heaps along the canal have long been reknowned for their wealth of fossils. Since S. C. Morton first described specimens from the area in 1829, a large number of authors have written about the paleontology of the Canal beds; most recently, papers include those of Groot, Organist & Richards (1954), Richards & Shapiro (1963), Owens *et al.* (1970), Pickett *et al.* (1972), Lauginiger & Hartstein (1981), Gallagher (1982), Lauginiger & Hartstein (1983), Lauginiger (1984), and Pickett *et al.* (1971).

The cycle of Cretaceous transgression and regression can be traced in the deposits along the Canal. Although the Army Corps of Engineers has graded, stabilized, and riprapped the Canal banks so that the once extensive exposures are largely gone, one can still collect abundant faunas from the spoil piles and a few limited outcrops. In general, the formations go from younger to older from east to west along the Canal; the sands and clays represent several cycles of sea-level variation. Today there are basically seven areas where fossils are found.

A. "Deep Cut," north bank of Canal between Summit Bridge and the Railroad Bridge -- This cliff section is the sole remaining example of the fine exposures that used to extend along much of the Canal. Unfortunately, this locality is in danger of being stabilized (*i.e.*, destroyed) by the Army Corps of Engineers. The cliff displays a complete transgressive-regressive cycle, from the marine

Merchantville Formation at the base, to the beach and nearshore sands of the Englishtown Formation in the middle, with marine glauconitic Marshalltown clay on top. The dark green micaceous Merchantville is best collected at low tide, when the mud flats are exposed and accessible. Typical Merchantville fossils include *Turritella* sp., ammonites (*Placenticeras, Menabites, Scaphites*), shark teeth, various pelecypods, and an unusually diverse and well-preserved fauna of crustaceans (Lauginiger & Hartstein, 1981). The lighter Englishtown quartz sand above the Merchantville clay is barren in its lower portion, but the top part of the formation is thoroughly burrowed. In addition to the *Ophiomorpha* burrows and other ichnofossils, Owens *et al.* (1970) have reported a varied estuarine and near-shore fauna in the top foot of the Englishtown. The Marshalltown represents a return to deeper water conditions and contains an extensive marine assemblage.

B. Tidal Flats, south bank between Summit Bridge and Cable Crossing -- At dead low tide, the flats here expose the Merchantville below the riprap. Especially notable are the large complete specimens of the ammonite *Placenticeras placenta* DeKay, with its distinct complex sutures. Other fossils found here include typical Merchantville forms such as *Turritella* sp., *Cardium tenuistriatum* Whitfield, *Gyrodes* sp., and shark teeth. Lignified wood is common, frequently found with *Teredo*-type borings in it.

C. Spoil Piles, north bank just northeast of Railroad Bridge -- This area contains a sort of fossil "stew"; the spoil heaps are dumped material that was dredged from the channel of the canal, so there is an admixture of faunas from several formations. Merchantville material seems to predominate, but occasional belemnite pens and *Exogyra* shells are probably from the Mount Laurel Formation. An interesting vertebrate fauna has been turned up from this site. In addition to the common shark teeth (mostly weathered *Scapanorhynchus* and *Squalicorax*), fish fossils include shark vertebrae, batoid vertebrae and teeth, sawfish rostral teeth (*Ischyrhiza mira* Leidy), the so-called "bean teeth" of the shell-crushing pycnodontid fish *Anomoeodus phaseolus* (Hay), large teeth (sometimes attached to jaw sections) of *Enchodus* sp., teleost vertebrae, and chimerid (ratfish) jaw sections. Reptile remains are rare and fragmentary but indicate the presence of turtles (*Trionyx* sp. and several other genera), crocodiles, mosasaurs (*Mosasaurus* sp. and *Globidens* sp., a shell-crushing type), hadrosaurian dinosaurs (Gallagher, 1982), and pterosaurs (Baird & Galton, 1981).

D. "Red Area," south bank between St. Georges and Summit Bridge -- The Army Corps of Engineers used to keep an officially-sanctioned fossil locality in a slump block on the bank of the canal marked with a red arrow. This is the "Red Area." Although its spatial extent is not very large, it does afford the opportunity to extract fossils directly and thus has advantages over the spoil heaps. Typical fossils include *Pycnodonte mutabilis* (Morton), *Agerostrea falcata* (Morton), *Exogyra* sp., *Panopea decisa* Conrad, *Cardium tenuistriatum* Whitfield, *Trigonia mortoni* Whitfield, *Anomia tellinoides* Morton, *Cucullaea* sp., *Turritella* sp., *Gyrodes* sp., *Baculites ovatus* Say, and *Cliona cretacica* Fenton & Fenton. This is a deeper-water (mid-shelf) assemblage; the dark greenish-gray glauconitic clay at this site is the Marshalltown Formation.

E. Spoil Piles on north bank west of St. Georges -- During construction of the St. Georges bridge in the mid-1960s, excavations on the south bank exposed sediments that were particularly rich in small shark teeth. Recent dredging has formed the spoil heaps on the north bank, and Lauginiger (1984) has described the varied microvertebrates from this locality, which also produced a hadrosaur tooth.

F. Biggs Farm, south bank east of St. Georges Bridge -- Years ago the Biggs Farm exposure was a series of fossil-rich bluffs along the canal. It has since been restricted to a small break in the riprap at water level, and is best collected at low tide. Richards & Shapiro (1963) and Owens *et al.* (1970) have compiled faunal lists for the Mount Laurel Formation at this locality. The Mount Laurel is a light gray glauconitic clayey medium-grained quartz sand, weathering to a tan or reddish-brown color. The fauna is characterized by a very diverse suite of pelecypods, gastropods, cephalopods, a scaphopod, numerous sponge borings (*Cliona* sp.), a coral (*Micrabacia cribraria* Stephenson), bryozoa, a brachiopod (*Terebratulina cooperi* Richards & Shapiro), polychaete worm tubes (*Hamulus* sp., *Serpula* sp.), decapod claws, and echinoids (*Phymosoma* sp., *Hemiaster* sp.). While many of the same forms are found in the New Jersey Mount Laurel--such as *Exogyra cancellata* Stephenson, *Pycnodonte mutabilis* (Morton), and *Belemnitella americana* (Morton), there is a unique element present in the Biggs Farm exposure. In particular the echinoids, coral, and bryozoa indicate a clear, more carbonate-rich environment probably characterized by normal marine salinities in shallow near-shore waters. *E. cancellata* is restricted to the Mount Laurel and hence is used to correlate its equivalents in the Atlantic and Gulf Coastal Plains south into Mexico.

G. Spoil Piles, north and south banks of canal just east of Reedy Point Bridge -- Dredge heaps on both sides of the canal near its entrance into the Delaware River provide abundant collecting. *Exogyra cancellata, Pyncnodonte mutabilis,* and the pens of *Belemnitella americana* are especially abundant. The spoil piles are primarily derived from the Mount Laurel Formation and represent material similar to the Biggs Farm fauna. Particularly noteworthy are the ammonite

specimens found here, including pieces of *Baculites ovatus* Say and fragments of the unusually-coiled heteromorph types such as *Solenoceras* and *Nostoceras*.

Age -- Merchantville, Englishtown, and Marshalltown Formations, Matawan Group, and Mount Laurel Formation, Monmouth Group, Upper Cretaceous (Campanian-lower Maestrichtian).

39. Holmdel, Monmouth County, New Jersey

Lithology -- Light brown glauconitic quartz sand overlain by grayish-green glauconitic sand.

Fossils -- A series of pits on the east side of Route 34 one to two miles south of Matawan expose the contact between the Mount Laurel Sand and the Navesink Formation. At the top of the lighter-colored quartz, just under the darker glauconite of the Navesink, a pebbly layer yields abundant shark teeth and crustacean claws. The overlying Navesink Formation also contains fossils. A typical fauna collected from these pits would include:

Porifera

Cliona cretacica Fenton & Fenton

Annelida

Hamulus sp.

Pelecypoda

Exogyra sp.
Ostrea falcata Morton
Pecten (Neitha) quinquecostata Sowerby
Cucullaea sp.

Gastropoda

Lunatia halli Gabb
Turritella sp.
Volutoderma biplicata (Gabb)
Gyrodes sp.

Cephalopoda

Belemnitella americana (Morton)

Arthropoda

Callianassa mortoni Pilsbry

Chondrichthyes

Ischyrhiza mira Leidy
Ischyodus sp.
Squalicorax pristodontis (Agassiz)
S. kaupi (Agassiz)
Scapanorhynchus texanus (Roemer)
Odontaspis holmdelensis Cappetta & Case
Cretolamna appendiculata (Agassiz)

The pebbly layer containing large decapod claws and abundant shark teeth is probably the same layer reported by Krinsley & Schneck (1964) at the top of the Mount Laurel; they interpreted this stratum as evidence of shoaling because of association with sand having textures typical of beach conditions. The regression of the Mount Laurel sea was superseded by the deeper water conditions of the glauconitic Navesink.

Nearby, at Hop Brook, a multituberculate mammal femur has been recovered from the Mount Laurel (Krause & Baird, 1979). This is the first known occurrence of a Cretaceous mammal in New Jersey. The femur was found in association with a vertebrate fauna similar to the one listed above.

Age -- Mount Laurel and Navesink Formations, Monmouth Group, Upper Cretaceous (Maestrichtian).

40. Mantua Creek, Sewell, Gloucester County, New Jersey

Lithology -- Indurated glauconitic quartz sand with pebbles and limonite layers.

Fossils -- During construction of the Gloucester County Sewage System, abundant Mount Laurel fossils were exposed along the north bank of a tributary to Mantua Creek just off Center Street in Sewell. This area is now heavily overgrown, but the fossiliferous layer is still observable in the stream bed and banks. The number of species (diversity) is limited, but individuals of these few types are abundant:

Porifera

Cliona cretacica Fenton & Fenton

Pelecypoda

Exogyra costata Say
E. cancellata Stephenson
Pycnodonte mutabilis Morton
Pecten sp.
Agerostrea falcata Morton

Cephalopoda

Belemnitella americana (Morton)

This is a typical Upper Cretaceous oyster reef assemblage characterized by a high-density, low-diversity ecology in nearshore intertidal to subtidal environment. The larger oyster genera, such as *Exogyra* and *Pycnodonte*, were recliners that lay just under the sediment surface with the large highly-convex valve down and the flat valve on top acting as a lid which the animal opened during feeding. LaBarbera (1981) performed an interesting experiment in which he dispersed models of these two genera in the western Gulf Coast of Florida. When he recovered his models, many of the artificial shells showed evidence of predation by decapod crustaceans; the models had fooled the crabs so completely that they attempted to eat the non-existent mollusks inside! Many Cretaceous oyster shells are broken and this may be due to duraphagous predation rather than transport. Indeed, LaBarbera credits the rise of shell-breaking predators, along with increases in bioturbation due to increased contribution of organic matter from marine angiosperms, with the eventual decline of recliners like *Exogyra* and *Pycnodonte*.

Evidence of the sponge *Cliona* is frequently observable in the latticework of burrows seen on *Exogyra*, *Pycnodonte*, and *Belemnitella*. Today, *Cliona* is found inhabiting dead and living oyster shells along the Atlantic continental shelf from Nova Scotia south to the Gulf of Mexico in subtidal environments down to a depth of 30 meters; the yellow sponge riddles the shell with its tunneling and is considered a pest on commercial oyster beds (Gosner, 1978). While it is not a parasite, the sponge can burrow a shell so thoroughly that the shell weakens and the mollusk dies. By living in the shell, *Cliona* obtains protection from currents and predation. Perhaps *Cliona cretacica* was also a contributory factor in the demise of the Cretaceous recliners by weakening the oysters and making them more susceptible to predation by crustaceans. Numerous "squid pens" of *Belemnitella americana* at this site attest to the tremendous abundance of this cephalopod in the Cretaceous seas. The squid-like animal probably swarmed in nektonic schools much like its modern relative.

Age -- Mount Laurel Formation, Monmouth Group, Upper Cretaceous (Maestrichtian).

41. Crosswicks Creek, Monmouth County, New Jersey

Lithology -- Glauconitic quartz sands with fine pebbles, and glauconite sands and clays.

Fossils -- Along the banks of Crosswicks Creek and its tributaries north of the Route 537 bridge near New Egypt there are a number of exposures of Upper Cretaceous fossiliferous beds. The old "Nutt Farm" locality of the literature is now off limits to collectors, but at this outcrop along a stream on the west bank of Crosswicks Creek a wide variety of fossils has been recovered from the upper part of the Mount Laurel Formation. These include:

Porifera

Cliona cretacica Fenton & Fenton

Annelida

Diploconcha cretacea Conrad

Crustacea

Callianassa mortoni (Pisbry)

Pelecypoda

Exogyra costata Say
E. cancellata Stephenson
Pycnodonte mutabilis Morton
Gryphaeaostrea vomer (Morton)
Agerostrea mesenterica Morton
A. falcata Morton
Crassatella sp.
Trigonia mortoni Whitfield
Cucullaea littlei (Gabb)
C. antrosa Morton
Cardium spillmani Conrad
C. tenuistriatum Whitfield
Anomia tellinoides (Morton)
Paranomia scabra (Morton)
Crassatellites vadosus (Morton)
Pecten sp.

Gastropoda

Lunatia halli Gabb
Turritella sp.
Bellifusus slacki (Gabb)
Odontofusus mucronata Gabb

Cephalopoda

Baculites sp.
Belemnitella americana (Morton)

Brachiopoda

Choristothyris plicata (Say)

In addition, vertebrate remains found here include indeterminate bone, shark teeth, and coprolites.

Immediately south of the Arneytown-Hornerstown Road bridge over the creek, in the west bank at stream level, there is an exposure of a typical Navesink shell bed. This site yields the usual oyster bank assemblage: *Exogyra costata*, *Pycnodonte mutabilis*, *Agerostrea falcata*, *A. mesenterica*, *Belemnitella americana*, and *Choristothyris plicata*. Further upstream on the east bank there are steep outcrops of a chocolate-colored heavily bioturbated glauconitic quartz sand with locally indurated ferruginous layers containing fossils. These are mostly poorly preserved steinkerns of *Lunatia*, *Pyropsis*, *Turritella*, *Exogyra*, *Pycnodonte*, and *Pecten venustus*. Minard & Owens (1962) map this exposure as the glauconitic facies of the Red Bank Formation. Olsson (1963) has proposed an alternative nomenclature for this unit, calling it the New Egypt Formation. This glauconitic formation is largely a down-dip subsurface deep-water facies that is correlated with exposed up-dip shallow-water facies including the Navesink, Red Bank, Tinton, and (in part) Hornerstown formations. Olsson stresses a facies interpretation of latest Cretaceous events, and discounts Weller's classic *Lucina-Cucullaea* faunal alternation as an indicator of changing water depth, preferring to explain faunal changes as functions of differences in sea-bottom environmental conditions such as substrate type. Certainly the upper part of the Mount Laurel Formation demonstrates a wide variety of facies. At locality 38F (Biggs Farm, C & D Canal) it is a highly diverse calcareous quartz sand. At locality 39 (Holmdel) it is a pebbly quartz beach sand with many shark teeth and decapod claws, probably the product of shoaling. At locality 40 (Mantua Creek), the upper Mount Laurel is a more glauconitic and indurated pebbly quartz sand with a low-diversity oyster bank assemblage. At the Nutt Farm, the contact between the Mount Laurel and Navesink reveals a very diverse mollusk fauna. It would seem that environmental conditions varied widely along the strike of this formation, at least during the latter part of its deposition.

Age -- Mount Laurel, Navesink, and New Egypt (= Red Bank) Formations, Upper Cretaceous (Maestrichtian).

42. Mullica Hill, Gloucester County, New Jersey

Lithology -- Pebbly quartz sand overlain by indurated glauconitic sand, superseded by green glauconite sand.

Fossils -- The Mullica Hill locality has been collected for over a century and is hence well-known in the literature. Today the owners of the property are sensitive about fossil collecting, and permission to examine the exposure must be obtained from the owners. The primary fossiliferous stratum is a shellbed at the base of the indurated New Egypt Formation. Fossils are also found in the underlying Mount Laurel, but this formation is mostly covered by slump and vegetation. At the top of the section, the Hornerstown greensand has reportedly yielded specimens (Richards, 1956), although no fossils are observable at present. A faunal list follows:

Porifera

Cliona cretacica Fenton & Fenton

Pelecypoda

Exogyra sp.
Pycnodonte mutabilis
Cucullaea neglecta
Agerostrea sp.
Crassatellites sp.

Gastropoda

Lunatia halli Gabb
Anchura pennata (Morton)
Gyrodes petrosa Morton
G. abyssina (Morton)
Volutomorpha conradi Gabb
Avellana bullata (Morton)
Pyropsis trochiformis (Tuomey)

Cephalopoda

Belemnitella americana (Morton)
Baculites sp.

Echinodermata

Nucleopygus? *gallagheri* Richards

In addition, Colbert (1948) reported hadrosaur remains from Mullica Hill.

The gastropod fauna is particularly abundant here, generally occurring as fairly well-preserved steinkerns. *Lunatia* is a member of the moon snail family, a group of active predators that feed upon pelecypods by rasping through their shells with radula teeth located on the gastropod's "tongue," aided by the secretion of a shell-dissolving acid. *Gyrodes* is another member of this carnivorous group. *Pyropsis* is a relative of the modern predaceous whelk, while *Volutomorpha* is an ancient member of the olive shell family, also carnivorous. *Anchura* was probably an epifaunal deposit feeder, crawling across the seafloor and eating detritus. The preponderance of predaceous gastropods fits in with the suggestion by LaBarbera (1981) that the Cretaceous recliners, such as the oysters, were decimated by the rise of shellfish carnivores.

Age -- Mount Laurel and New Egypt Formations, Monmouth Group, Upper Cretaceous (Maestrichtian).

43. Big Brook, Marlboro, Monmouth County, New Jersey

Lithology -- Dark green clayey glauconite sand overlain by orange-brown quartz sand.

Fossils -- Long a famous area for collecting shark teeth from the stream gravels, the extensive exposures of greensand marl along the banks of Big Brook are also abundant in the characteristic Navesink oyster bank assemblage. At least two different shell beds can be observed in the outcrop. Typical invertebrates found here are *Exogyra costata, Pycnodonte mutabilis, Agerostrea mesenterica*, pieces of gastropod steinkerns (*Turritella, Gyrodes*), guard shells of *Belemnitella americana*, borings of *Cliona cretacica*, claws of *Callianassa mortoni*, and the small brachiopod *Choristothyris plicata*. The highly plicated commissure of *C. plicata* may have been an adaptation to sandy environments where suspension feeders must strain out smaller food particles while excluding coarser sand grains. In this regard it is interesting to note that the small oyster *Agerostrea* also has a complexly crenulated shell margin.

Vertebrates at this site include many shark teeth, primarily *Squalicorax* and *Scapanorhyncus*, ray teeth, sawfish rostral teeth (*Ischyrizus mira*), and various pieces of indeterminate bone. Especially significant is the occurrence here of an armor scute from an ankylosaur; this is not identifiable on the generic level, but represents the first known fossil of these dinosaurs from the East Coast (Baird & Horner, 1977).

In addition, Ralph Johnson of the Monmouth Amateur Paleontologists Society (MAPS) has found the femur of the ostrich-mimic dinosaur *Ornithomimus antiquus* in the Mount Laurel/Wenonah deposits along a tributary of Big Brook just upstream from the main Navesink fossiliferous exposures (Baird, personal communication). It is probable that many of the shark teeth and perhaps some of the other fossils found in the stream bed are derived from the Mount Laurel/Wenonah exposures farther upstream.

The glauconitic Navesink represents a deepening of the sea from the Mount Laurel regression and conditions in the Navesink are interpreted as middle to outer shelf environments (Owens & Sohl, 1969). The overlying Red Bank Formation was deposited in shallower waters and fossils are rarely found in it.

Age -- Wenonah Formation (Campanian); Mount Laurel, Navesink, and Red Bank Formations, Upper Cretaceous (Maestrichtian).

44. Poricy Brook, Middleton, Monmouth County, New Jersey

Lithology -- Dark green clayey glauconite sand overlain by orange-brown micaceous quartz sand.

Fossils -- Along Poricy Brook two and a half miles south of Middleton on the Middleton-Lincroft Road (Church Street), the township has established an official paleontological park. Again, the Navesink exposure demonstrates the high-density, low-diversity characteristics of the Navesink oyster bank ecosystem, with abundant specimens of *Exogyra costata, Pycnodonte mutabilis, Agerostrea mesenterica, Pecten venustus, Belemnitella americana*, and *Choristothyris plicata*. Owens & Sohl (1969) regard this as the upper part of the Navesink; they also report fossils from the basal part of the Red Bank at this site.

It should be noted that a tail vertebra from an ankylosaur has been found at Poricy Brook (Baird, personal communication).

Age -- Navesink and Red Bank Formations, Monmouth Group, Upper Cretaceous (Maestrichtian).

45. Atlantic Highlands, Monmouth County, New Jersey

Lithology -- Dark grayish-green clayey glauconite sand overlain by orange-brown medium-grained micaceous quartz sand.

Fossils -- In the bluffs along Raritan Bay, the cuesta separating the Inner Coastal Plain from the Outer Coastal Plain has been dissected by erosion to reveal a section of Upper Cretaceous strata. Cobban (1974) has recorded a unique ammonite fauna from the base of the Navesink Formation here; most of the specimens he studied were collected by members of the Monmouth County Amateur Paleontological Society. The ammonites were found in two distinct layers at the bottom of the Navesink; these horizons are generally covered by slump at the present. Cobban's faunal ammonite list is given below:

Baculites ovatus Say
B. claviformis Stephenson
Nostoceras helicinum (Schumard)
N. hyatti Stephenson
N. cf. *N. stantoni* Hyatt
N. pauper (Whitfield)
N. mendryki Cobban
Axonoceras cf. *A. angolanum* Haas
Exiteloceras oronense (Lewy)
Didymoceras navarroense (Shumard)
Hoploscaphites pumilus (Stephenson)
Hoploscaphites sp.
Pachydiscus sp.

Reviewing the stratigraphic range of these forms, Cobban concludes that the base of the Navesink at this locality is close to the Campanian-Maestrichtian boundary. Field investigations by this author revealed that these layers also contain numerous large steinkerns of pelecypods (*Exogyra, Cardium, Paranomia, Cucullaea*), gastropods (*Gyrodes, Turritella, Lunatia, Pyropsis*), phragmocones of *Belemnitella americana, Callianassa mortoni* claws, pieces of echinoderm (*Catopygus williamsi*?), *Cliona cretacica* borings, shark teeth, sawfish rostral teeth, and mosasaur vertebrae.

The presence of a diverse nektonic ammonite fauna suggests considerable water depth for the Navesink sea. Olsson (1963) has proposed a depth of 180-350 feet based on planktonic studies. The overlying Red Bank is well-exposed to the east of the Navesink outcrop and upward in the section; there are no apparent macrofossils contained in it. Miller (1956) shows a photograph depicting interfingering between the Navesink and the Red Bank. As noted earlier in this paper, Olsson (1963) has offered a facies interpretation of latest Cretaceous deposition in New Jersey. Others, such as Miller and Gill *et al.* (1969) have supported such a view. Specifically, Gill *et al.* have proposed that the axis of maximum deltaic sedimentation moved northward in this area during the Cretaceous, with early Cretaceous Potomac deposits, early to middle late Cretaceous Delaware and Schuylkill deltas, and middle to late Cretaceous Hudson deltaic sedimentation. Perhaps the Red Bank at this site represents the ancestral Hudson sedimentary influx.

The first record of flying reptiles in New Jersey is a large vertebra unearthed by Ralph Johnson from the basal shell bed at this locality; it is believed to belong to the family Titanopterygidae, and is classified by Baird (personal communication) as *Titanopteryx* sp. This form is related to the giant pterosaur *Quetzalcoatlus* from Texas, the largest flying animal known.

Age -- Navesink and Red Bank Formations, Monmouth Group, Upper Cretaceous (Maestrichtian).

46. Mantua Creek, Barnsboro, Gloucester County, New Jersey

Lithology -- Dark green clayey glauconitic sand, pebbly and with indurated ferruginous layers toward the top of the section.

Fossils -- In tributaries of Mantua Creek along Route 553 (Alternate), stream bank exposures contain numerous fossils. Typical specimens found here include *Exogyra, Agerostrea, Gryphaeaostrea, Gyrodes, Anchura, Belemnitella,* and *Baculites*. Recently, an important discovery of the first known crinoid from the Cretaceous of New Jersey was made by Michael Bernstein at this site. The specimen consists of a number of articulated columnals in a glauconitic matrix associated with *Belemnitella* guard shells.

It was from this place in 1866 that E. D. Cope obtained the remains of *Dryptosaurus* ("*Laelaps*") *aquilunguis*, a large carnosaur characterized by particularly impressive claws on its feet. Cope also collected a hadrosaur (*"H. cavatus" = Edmontosaurus minor* Marsh) from the same locality, an old marl pit (Osborn, 1931; Baird, personal communication).

Age -- New Egypt Formation, Monmouth Group, Upper Cretaceous (Maestrichtian).

47. Beers Hill, Hazlet, Monmouth County, New Jersey

Lithology -- Orange-brown quartz sand overlain by green pebbly glauconitic sandstone with layers of vivianite.

Fossils -- A road cut on Holmdel Road near the Bell Telephone Laboratory reveals Maestrichtian beds. The underlying reddish-brown sands are devoid of fossils, but the coarse indurated glauconitic quartz sand above it contains *Exogyra, Cardium,* and *Callianassa* claws. The *Exogyra* shells are frequently found replaced by vivianite, a dark blue secondary phosphate. The other fossils are generally poorly preserved steinkerns. The Red Bank sand may have been deposited under an oxidizing environment, while the overlying glauconitic unit, the Tinton Formation, was probably the product of reducing marine conditions. It must have been a shallow marine environment, however, as indicated by the high content of coarse clastic material. The Tinton is cemented by siderite (Owens & Sohl, 1969).

Age -- Red Bank and Tinton Formations, Monmouth Group, Upper Cretaceous (Maestrichtian).

48. Tinton Falls, Monmouth County, New Jersey

Lithology -- Dark green coarse glauconitic sandstone with fine pebbles and siderite.

Fossils -- The falls of Pine Brook in the town of Tinton Falls are an unusual feature in the New Jersey Coastal Plain with its generally unconsolidated sediments. The falls are developed on a ledge of the indurated Tinton Formation which contains numerous marine invertebrate fossils. The specimens are poorly preserved steinkerns coated with siderite; the fauna includes pelecypods (*Exogyra, Cardium, Cucullaea, Pecten venustus*), gastropods (*Pyrifusus*), an ammonite (*Sphenodiscus lobatus*), and abundant claws of *Callianassa mortoni*. The copious quantities of large decapod claws along with the high content of coarse clastics, is further evidence that the Tinton was deposited in a shallow-water near-shore environment, perhaps quite close to beaches where wave and tidal action concentrated the ghost shrimp claws. The ammonite *Sphenodiscus* is interesting because it is widely accepted as a zone fossil for the Maestrichtian.

Age -- Tinton Formation, Monmouth Group, Upper Cretaceous (Maestrichtian).

49. Blackwood Terrace, Gloucester County, New Jersey

Lithology -- Yellowish-brown to gray-green poorly sorted clayey glauconitic sand with small quartz pebbles and limonite layers, overlain by grayish olive green well-sorted massive glaucontite sand (greensand).

Fossils -- For several years (1977-1979) the cuesta at Blackwood Terrace revealed the best exposure of the New Egypt-Hornerstown contact in New Jersey. During that time this author made detailed stratigraphic and faunal studies. Since then the exposure has been bulldozed and graded; while fossils are still abundant here, there is no longer good control on their stratigraphic origin Therefore, it seems desireable to present a good stratigraphic description along with an annotated faunal list.

Thickness of Interval	Lithology
3.9 m	Slumped and disturbed orange-brown gravels; Pennsauken Formation
3.3 m	Grayish olive green glauconite sand; Hornerstown Formation, "bone bed" at base
5.8 m	Brown to gray-green glauconite sand; New Egypt Formation, shellbed at base
1.5 m	Light brown quartz sand with fine pebbles; Mount Laurel Formation

An annotated faunal list follows on the next page.

Certain associations of fossils are worth mentioning. The oyster types (*Exogyra, Pycnodonte, Agerostrea*) occur in their greatest numbers in the shellbed along with *Choristothyris, Belemnitella, Baculites,* and *Cliona*; this seems to be a highly weathered version of the widespread New Egypt oyster bank assemblage. In particular, its lithology, mode of preservation, and faunal content are strongly reminiscent of the shellbed at Mullica Hill (locality 42). Above the shellbed the New Egypt is thoroughly bioturbated, with carbonate mottling indicating burrows and/or shell ghosts; scattered mollusk steinkerns in this upper part of the formation are usually limonitized, broken, and poorly preserved. The contact between the New Egypt and the Hornerstown at 5.8 meters above the shellbed is marked by extensive burrowing; the burrows are generally filled with darker, more glauconitic, greensand than is the surrounding material. Indurated limonite forms a conspicuous layer at the contact and is probably the result of precipitation of iron in ground water due to permeability differences between the two formations. About 0.2 meter above the contact there is a thin concentration of fossils particularly rich in vertebrates, hence the appellation "bone bed." Small bleached shark teeth and abundant reptile bone pieces are generally found in close association with numerous specimens of *Cucullaea*. *C. vulgaris* ranges throughout the New Egypt up into the Hornerstown, but its concentrated populations found with crocodile and turtle remains, usually as complete double-valved individuals (as opposed to the generally single-valved or broken specimens in the Navesink), seem to suggest that the decaying organic remains of the vertebrates provided ideal trophic conditions for the clams. Fossils are rare in the interval above this bed until a more diffuse fauna is encountered at the top of the formation; this association consists of the sponge *Peridonella*, the coral *Flabellum*, and lamnoid shark teeth and vertebrae.

Somewhere within this section is the Cretaceous-Tertiary interface. The New Egypt shellbed with its ammonites and mosasaurs is unquestionably Cretaceous; the top of the Hornerstown contains

Blackwood Terrace Fauna

	Porifera
Cliona creticica Fenton & Fenton	As crusts on shells from shellbed at base of New Egypt; boring suspension feeder
Peronidella dichotoma (Gabb)	From upper part of Hornerstown; epifaunal suspension feeder
	Coelenterata
Flabellum mortoni Vaughan	From upper part of Hornerstown; ahermatypic epifaunal carnivore and/or suspension feeder
	Annelida
Polychaete worm tubes	New Egypt shellbed; infaunal suspension feeder
	Brachiopoda
Choristothyris plicata (Say)	New Egypt shellbed; epifaunal suspension feeder
	Pelecypoda
Exogyra cf. *costata* Say	Most abundant in New Egypt shellbed; reclining infaunal suspension feeder
Pycnodonte cf. *mutabilis* Morton	Poorly preserved ferruginous and phosphatized steinkerns from New Egypt and Hornerstown; reclining infaunal suspension feeder
Gryphaeostrea vomer Morton	New Egypt Formation; juvenile form of *Pycnodonte*? suspension feeder
Agerostrea nasuta (Morton)	Shellbed and upper part of New Egypt; probably a variety of *A. mesenterica*; epifaunal suspension feeder
Cucullaea vulgaris Morton	New Egypt and Hornerstown; partially infaunal suspension feeder
Trigonia mortoni Whitfield	New Egypt shellbed; infaunal suspension feeder
Various indeterminate partial steinkerns	New Egypt and Hornerstown
	Gastropoda
Anchura pennata (Morton)	New Egypt; epifaunal deposit feeder
Gyrodes abyssinus (Morton)	New Egypt; epifaunal carnivore
Turritella vertebroides Morton	New Egypt and Hornerstown; infaunal deposit feeder and/or herbivore
Lunatia halli Gabb	New Egypt; epifaunal carnivore
Pyropsis sp.	New Egypt; epifaunal carnivore
	Cephalopoda
Eutrephoceras dekayi (Morton)	Found as float; stratigraphic position indeterminable; nektonic carnivore
Belemnitella americana (Morton)	Phragmocone steinkerns abundant in New Egypt shellbed; nektonic carnivore
Baculites ovatus Say	New Egypt shellbed; nektonic carnivore
Unbilical coils of planispiral ammonite, species indeterminate	New Egypt; nektonic carnivore

(cont'd)

	Echinodermata
Catopygus williamsi Clark	New Egypt shellbed; infaunal deposit feeder
	Chondrichthyes
Ischyodus sp.	Jaw section of chimeroid (ratfish); New Egypt; nektonic carnivore
Ischyriza mira Leidy	Found as float; nektonic carnivore
Scapanorhyncus texanus (Roemer)	Found as float; probably from both New Egypt and Hornerstown; nektonic carnivore
Squalicorax pristodontus Morton	Found as float; probably from both New Egypt and Hornerstown; nektonic carnivore
Batoid vertebrae	New Egypt Formation; nektonic carnivore, possibly duraphagous
	Osteichthyes
Anomoeodus (Pycnodus) phaseolus Hay	"Bean teeth" from New Egypt; nektonic carnivore, probably duraphagous
Enchodus ferox Leidy	Found as float; nektonic carnivore
	Reptilia
Turtle plastron and part of carapace	Hornerstown "bone bed"; nektonic carnivore
Thoracosaurus sp.	Partial lower jaw, with teeth; Hornerstown "bone bed"; nektonic carnivore
Mosasaur remains	Including numerous teeth of various sizes, sections of rostrum, portions of skull, dorsal and caudal vertebrae; all probably from New Egypt Formation; nektonic carnivore

a Paleocene fauna. Since the exposure is thoroughly covered, further investigations are impossible at this site at the moment, although future excavations may once again uncover the sequence.

Age -- New Egypt Formation, Monmouth Group, Upper Cretaceous (Maestrichtian), and Hornerstown Formation, Cretaceous?-Paleocene (Danian).

50. Inversand Company Marl Pit, Mantua Township, Gloucester County, New Jersey

Lithology -- Dark brown clayey glauconitic sand ("chocolate marl") overlain by grayish olive green glauconite sand ("greensand").

Fossils -- The Inversand Company's pit near Sewell is the last remnant of a once-thriving industry in New Jersey, the mining of greensand marl. Although the glauconite dug here is used for water softener, its chief use in the nineteenth century was as fertilizer. Over the years, the Inversand pit has yielded an intriguing fauna. Most of the material has come out of a thin layer near the base of the Hornerstown Formation. The age of this Main Fossiliferous Layer (or MFL; also referred to in previous literature as the "Middle Greensand" or the "Bonebed") has been the subject of some disagreement. Originally, Weller (1907) assigned the Hornerstown, along with the Vincentown and Manasquan Formations above it, to the Upper Cretaceous; in this he was following the practice of previous workers. Cooke & Stephenson (1928), however, reassigned these three units to the Eocene. Since then the Hornerstown was moved down into the Paleocene by Spangler & Peterson (1950), and this has become the traditional view, as supported by Minard *et al.* (1969), Owens & Sohl (1969), Owens *et al.* (1970), and Owens & Sohl (1973). A number of authors have questioned the propriety of a Paleocene age for the lower Hornerstown fossiliferous layer (Miller, 1956; Olsson, 1963; Baird, 1964, 1967; White, 1972; Gallagher, 1974; Koch & Olsson, 1974, 1977; Richards & Gallagher, 1974; Olson & Parris, in press). This criticism is largely based on the faunal content of the MFL at the Inversand pit. While the U.S. Geological Survey has favored an angular unconformity along the strike from northeast to southeast, with the disappearance of successively younger beds from the Raritan Bay area southward to the Chesapeake and Delaware Canal, they have also attempted to explain

the distinctly Cretaceous faunal aspect of the MFL in terms of reworking from lower beds. The macrofossil and microfossil evidence is not in agreement with this interpretation; facies changes can be invoked to explain the differences in lithology along strike, and it has been pointed out that the fragile nature of some of the specimens of Cretaceous affinities argues against erosional reworking of the fossils from underlying strata into the MFL (Richards & Gallagher, 1974). Moreover, the Cretaceous fauna of the MFL is not characteristically related to underlying Cretaceous formations; it seems to be a distinct assemblage (Parris, personal communication), perhaps representing the last individuals of uppermost Maestrichtian age. Seen in these terms, the MFL at Sewell (and elsewhere, as previously exposed at Blackwood Terrace, locality 49) becomes an invaluable window into the Cretaceous-Tertiary extinction problem. In the New Egypt "chocolate marl" (= Navesink Formation of previous authors) at the Inversand pit there is a fauna of mosasaurs (Chafee, 1939), hadrosaurs (Cobert, 1948), and a few scattered mollusks, including most commonly *Agerostrea nasuta* (which is probably a steinkern variety of *A. mesenterica*). Recently, this bed, about two meters below the contact with the Hornerstown Formation, has yielded an arthritic hadrosaur tibia and fibula as well as more mosasaur remains. From 7.5 to 9 cm above the contact between the New Egypt and the Hornerstown, the beginning of the MFL is marked by a layer of oysters; this horizon, and the contact below, is thoroughly bioturbated. The heaviest concentration of fossils is around 32 cm above the contact. A list of MFL fossils from Olson & Parris (in press) includes the following taxa:

Invertebrata

Brachiopoda

Terebratulina atlantica Morton

Gastropoda

Gyrodes abyssinus Morton
Acteon cretacea Gabb
Anchura abrupta Conrad
Turbinella parva Gabb
T. subconica Gabb
T. vertebroides Morton
Lunatia halli Gabb
Pyropsis trochiformis Tuomey
Volutoderma ovata Whitfield

Pelecypoda

Cardium tenuistriatum Whitfield
Glycymeris mortoni Conrad
Pycnodonte convexa Say
Gervilliopsis ensiformis Conrad
Gryphaeostrea vomer Morton
Panopea decisa Conrad
Veniella conradi Morton
Crassatella vadosa Morton
Cucullaea vulgaris Morton
Lithophaga ripleyana Gabb
Xylophagella irregularis Gabb
Nuculana stephensoni Richards
Etea delawarensis Gabb

Nautiloidea

Eutrephoceras dekayi Morton

Ammonoidea

Baculites ovatus Say
Sphenodiscus lobatus Tuomey
Pachydiscus (Neodesmoceras) sp.

Crustacea

cf. *Hoploparia* sp.

Vertebrata

Chondrichthyes

Lamna appendiculata Agassiz
Odontaspis cuspidata Agassiz
Squalicorax pristodontus Morton
Hexanchus sp.
Edaphodon stenobyrus Cope
E. mirificus Leidy
Ischyodus cf. *thurmanni* Pictet & Campiche
Squatina sp.
Myliobatis cf. *leidyi* Hay
Ischyrhiza mira Leidy
Rhinoptera sp.
cf. *Rhombodus levis* Capetta & Case

Osteichthyes

Enchodus cf. *ferox* Leidy
E. cf. *serrulatus* Fowler
Paralbula casei Estes

Chelonia

Adocus beatus Leidy
Osteopygis emarginatus Cope
Taphrospys molops Cope
T. sulcatus Leidy
cf. *Dollochelys* sp.

Crocodilia

cf. *Procaimanoidea* sp.
Hypsosaurus sp.
Thoracosaurus sp.
Bottosaurus harlani Meyer
Diplocynodon sp.

Lacertilia

Mosasaurus sp.

Aves

Eight specimens of birds, including an articulated wing

Two to three meters above the MFL, a typically Paleocene fauna occurs (Parris, personal communication):

Porifera

Peronidella dichotoma (Gabb)

Coelenterata

Flabellum mortoni

Brachiopoda

Terebratulina atlantica Morton

Pelecypoda

Cucullaea sp.

Chondrichthyes

Lamnoid shark teeth
Edaphodon sp.

Reptilia

Dolochelys sp.--turtle
Hypsosaurus sp.--crocodile

This is definitely a Midway (= Danian) assemblage, with little similarity to the Cretaceous fauna below it in the MFL. The ammonites, mosasaur, and birds (which are of Cretaceous affinities; Parris, personal communication) are distinctively Cretaceous while many of the mollusks are typically Cretaceous forms. Koch & Olsson (1977) have used dinoflagellate zones to verify the Cretaceous age of the MFL; their micropaleontological work indicates that there is no angular unconformity along the strike between the Hornerstown greensand and underlying units. It would seem likely that the MFL at the Inversand pit represents a deeper-water facies of Olsson's New Egypt Formation. There appears to be no break in sedimentation upward into the Danian upper Hornerstown, so that the MFL fossils may represent the very last representatives of Mesozoic biota existing at the time of the Mesozoic-Tertiary extinction. The transition from the MFL to the Danian is a typical Cretaceous-Tertiary boundary contrast between larger, more diverse and abundant faunas, and generally smaller individuals of a much less abundant and less diverse Paleocene assemblage. Perhaps a search for an iridium-rich layer in this section would clarify the nature of of the Cretaceous-Tertiary boundary in this area.

Age -- New Egypt Formation (= "Navesink") plus lower Hornerstown MFL , Upper Cretaceous (late Maestrichtian), and upper Hornerstown, Paleocene (Danian).

Cenozoic Era

TERTIARY PERIOD. After the general regression at the end of the Mesozoic, the interior of North America was never again widely submerged. The Laramide Orogeny produced the Rocky Mountains, and tectonism elsewhere in the world had drained the widespread epeiric seas. The eastern seaboard was still low, however, and further oscillations of sea level occurred, producing a series of transgressions in the early Tertiary. These inundations are recorded in a sequence of glauconitic beds somewhat similar in appearance to the Upper Cretaceous, but distinct from them in paleontology.

Because of the widespread and well-represented nature of the Cenozoic deposits, the Tertiary Period has been divided into subsidiary units called epochs. During the Paleocene and Eocene Epochs the sea overlapped the Gulf and Atlantic Coastal Plains and marine strata were deposited. The Oligocene Epoch saw a withdrawal of the sea, and beds of this age are not represented in the Delaware Valley area. The Miocene Epoch brought a brief resubmergence of the East Coast, while in the American West renewed uplift was accompanied by large-scale volcanic activity. During the Pliocene Epoch, worldwide climate grew cooler and more arid; little if any marine deposition occurred in the area with which we are concerned.

Throughout this period, mammals diversified into many forms, some of them quite bizarre. Early in the Cenozoic, mammals were accompanied in their dominance of terrestrial habitats by several varieties of large flightless birds. With the advent of the grasses in the Miocene, most of the modern angiosperm groups had appeared.

Marine life gradually assumed its modern aspect, and it was on the basis of the proportion of modern mollusks found in Cenozoic beds of the Paris Basin that Charles Lyell originally subdivided the Cenozoic into epochs. Major oceanographic changes that affected marine biota were probably caused by the further restriction of Tethyan currents, and by the raising of the Isthmus of Panama later in the period.

51. Tributary of Big Timber Creek, Stratford, Camden County, New Jersey

Lithology -- Grayish olive green glauconite sand with indurated iron-rich layers.

Fossils -- Steinkerns of brachiopods and pelecypods are found in a small tributary of Big Timber Creek near the intersection of Warwick Road and Laurel Road. A faunal list includes the following representative taxa:

Porifera

Peronidella dichotoma (Gabb)

Brachiopoda

Oleneothyris harlani (Morton)

Pelecypoda

Etea delawarensis (Gabb)
Gryphaeostrea vomer (Morton)
Cucullaea sp.

Cephalopoda

Eutrophoceras dekayi (Morton)

Chondrichthyes

Large (2-3 in.) lamnoid shark teeth

Reptilia

Bone material, probably crocodilian

The diversity of this fauna is much reduced from the underlying Cretaceous beds. The nautiloid *E. dekayi* is noteworthy as a survivor from the Maestrichtian; while its more specialized ammonite relatives became extinct, this generalist form (widespread but never extremely abundant) managed to escape the Cretaceous-Tertiary extinction.

Age -- Upper Hornerstown Formation, Paleocene (Danian), Tertiary.

52. Southwest branch of Rancocas Creek, Marlton, Burlington County, New Jersey

Lithology -- Grayish olive green glauconite sand.

Fossils -- Various construction projects in the vicinity of the intersection of the southwest branch of Rancocas Creek with Route 70 have, over the years, yielded numerous specimens. At the time of this writing, exposures are limited, but fossils are available in one small outcrop along a small tributary flowing east into the Rancocas immediately adjacent to the highway, as well as in spoil piles along the stream's east bank south of Route 70. Typical fossils include:

Porifera

Peronidella dichotoma (Gabb)

Brachiopoda

Oleneothyris harlani (Morton)

Coelenterata

Flabellum mortoni Vaughn

Pelecypoda

Gryphaea dissimilaris
Gryphaeostrea vomer (Morton)
Cucullaea sp.
Polorthus tibialis (Morton)--pelecypod tubes

Gastropoda

Turritella sp.

Chondrichthyes

Shark teeth

Reptilia

Crocodilian bone

This is obviously a marine fauna, and the lithology seems to indicate that water depth was comparable to the deeper phases of the Cretaceous sea in this area. In some of the previous exposures in this vicinity, particularly in the old Zeolite Chemical Company greensand pit nearby in Medford, fragments of crocodile bones were very common, demonstrating that these large reptiles had continued to thrive after the great extinction.

Age -- Upper Hornerstown Formation, Paleocene (Danian), Tertiary.

53. Shingle Run, New Egypt, Monmouth County, New Jersey

Lithology -- Dark olive gray glauconitic sand with locally indurated shellbeds.

Fossils -- Along the banks of this small tributary to Crosswicks Creek the best exposures of the *Oleneothyris* biostrome can be seen. This brachiopod occurs in great abundance almost to the exclusion of all other macrofossils; the only other specimens found here are less common valves of *Gryphaea dissimilaris* and occasional pieces of bryozoa and coral. This high-density, low-diversity community has been studied by Feldman (1977), who recognized two principle morphotypes of *Oleneothyris harlani* here. One variant (Feldman's Type A) is a flatter, wider form with a smaller pedicle opening and a smoother commissure; the other variant (Feldman's Type B) is a more convex, cylindrical shell with a larger pedicle opening and a strong sulcus wrinkling the commissure. Feldman interpreted his statistical treatment of the variation in *O. harlani* shell parameters as an example of evolutionary adaptation by an opportunistic generalist species to environmental disturbance, probably increasing current or wave action associated with a shallowing of the late Hornerstown sea. The upper part of the Hornerstown at this site is more sandy, and the larger type B individuals seem to be more common upward in the exposure; these are the types that Feldman asserts were better adapted to wave and current disturbance. But while the upper layer contains mostly articulated individuals probably representing a biocoenosis, the lower part of the section contains more broken and disarticulated brachiopod valves, primarily of Type A smaller shells. This lower layer could also be interpreted as a higher-energy environment where shells were concentrated in a thanatocoenosis. It is possible that the variations in shell form could be ascribed to sexual dimorphism or to standard genetic variation in the brachiopod population.

Minard & Owens (1962) map the *Oleneothyris* biostrome as the boundary between the Hornerstown and the overlying Vincentown Formation. While they place the biostrome at the base of the Vincentown, other authors (Richards, 1956; Wolfe, 1977) have referred it to the Hornerstown, and it is possible that the organic layer is time-transgressive, reflecting diachronous sea-level fluctuations

Age -- Upper Hornerstown Formation, Paleocene (Danian), Tertiary.

54. South Branch of Rancocas Creek, Vincentown, Burlington County, New Jersey

Lithology -- Cream-colored to light brown highly fossiliferous limesand with indurated limestone layers.

Fossils -- The calcareous facies of the Vincentown Formation is exposed in the type area along the banks of the Rancocas near the local sewage plant. While this facies is common lower in the formation and to the south in its outcrop belt, a quartz sand facies predominates higher in the formation and to the north (Lewis & Kummel, 1940). Characteristic fossils found here include the following taxa:

Foraminifera

Nodosaria zippei Reuss
Globigerinids

Coelenterata

Flabellum mortoni Vaughn
Trochocyathus sp.
Graphularia ambigua Morton
Hermatypic coral, spp. indet.

Bryozoa

Coscinopleura digitata Morton
Numerous other species--see Canu & Bassler (1933) or Greacen (1941) for extensive lists

Annelida

Rotularia rotula (Morton)

Pelecypoda

Gryphaea dissimilaris Weller
Graphaeostrea vomer Morton
Polorthus tibialis Morton
Arca quindecemradiata Gabb

Gastropoda

Volutoderma sp.

Echinodermata

Echinoid spines and basal plates
Pentacrinus bryani Gabb
Cidaris splendens Morton

Chondrichthyes

Lamna sp.

In addition, Miller (1955) reports that bird bones and some fossil snake remains were found in Vincentown a number of years ago. The remarkable feature of this particular exposure is the abundance and diversity of bryozoa. *Coscinopleura digitata*, a cheilostome, is the most common species,

but Canu & Bassler (1933) and Greacen (1941) list numerous others. Another interesting aspect of the fauna are the large nodosarid and globigerinid foraminifera, easily visible to the unaided eye. Various hermatypic and ahermatypic corals as well as frequent crinoid and sea urchin remains help complete the ecologic picture. This assemblage suggests a reef environment, with relatively shallow waters, low terrigenous input, and warm temperatures. The high-diversity reef community offers a nice contrast to the high-density, low-diversity *Oleneothyris* biostrome of the subjacent Hornerstown Formation. Carbonate deposition was not ubiquitous in the Vincentown, however, and the quartz sand facies may represent areas where terrigino-clastic sedimentation predominated due to river input. The assemblage at this site may represent hydrodynamic sorting, leading to a thanatocoenosis; the abundant broken-up bryozoan pieces indicate transport by tidal or wave-initiated currents. The numerous disarticulated echinoid elements support this conclusion.

Age -- Vincentown Formation, Paleocene (Danian), Tertiary.

55. Medford Farms, Medford, Burlington County, New Jersey

Lithology -- Light gray limesand.

Fossils -- Excavations for irrigation ponds at Medford Farms Nurseries along Church Road have produced richly fossiliferous spoil piles. The spoil piles are difficult to get to, and permission should be obtained from the owner first. Fossils are even more diverse and abundant than at Vincentown, and the spoil heaps contain the following typical forms:

Foraminifera

Nodosaria zippei Reuss
Various globigerinids, spp. indet.

Coelenterata

Flabellum mortoni Vaughn
Graphularia ambigua Morton

Bryozoa

Coscinopleura digitata Morton
Many other forms, primarily encrusting types

Annelida

Rotularia rotula (Morton)

Pelecypoda

Kummelia mortoni (Gabb)
Polorthus tibialis (Morton)
Gryphaea dissimilaris Weller
Graphaeostrea vomer Morton
Arca quindecemradiata (Gabb)
Cardium cf. *C. knappi* Weller
Meretrix cf. *M. ovata* (Conrad)
Panopea sp.

Gastropoda

Cavoscala annulata (Morton)
Volutoderma sp.
Pyropsis? sp.

Arthropoda

Scalpellum conradi Gabb

Echinodermata

Cidaris splendens Morton
Salenia tumidula Clark
Hemiaster sp.
Linthia tumidula Clark

Chondrichthyes

Lamna sp.--teeth

The most notable difference between this fauna and that of the preceding locality (No. 54) is the common presence of the gastropod *Cavoscala annulata*, a member of the wentletrap family (Epitoniidae). It is known that some modern members of this family ingest foraminifera (Abbott, 1968), and perhaps *C. annulata* fed on the numerous large forams found in association with it.

Age -- Vincentown Formation, Paleocene (Danian), Tertiary.

56. Timber Creek, Clementon, Camden County, New Jersey

Lithology -- Medium-green glauconitic quartz sand with clay.

Fossils -- Along the bank of a tributary to Timber Creek the next youngest formation in the area, the Manasquan Formation, is exposed. The specimens are all mollusks and include:

Pelecypoda

Gryphaea dissimilaris Weller
Gryphaeostrea vomer Morton
Arca quindecemradiata Gabb
Etea delawarensis (Gabb)

Gastropoda

Turritella sp.

Glauconitic deposition in this unit would seem to suggest that the cycle of deposition had swung back to a transgressional phase with water generally deeper than in Vincentown time.

Age -- Manasquan Formation, Lower Eocene (Wilcox), Tertiary.

57. Manasquan River, Squankum, Monmouth County, New Jersey

Lithology -- Coarse-grained glauconitic sandstone.

Fossils -- Bluffs along the Manasquan River reveal an indurated sandstone containing many specimens of the pelecypod *Venericardia antiquata*. Shark teeth are also occasionally found. Here again we have a low-diversity assemblage with one species overwhelmingly dominant. This is typicall the case in disturbed or stressed environments; *V. antiquata* may have been a generalist species adapted to a sandy nearshore bottom where wave and current action were intense.

Years ago the bones of the giant flightless bird *Diatryma regens* were uncovered at Squankum; remains of a snake (*Paleophis*) and a primitive ungulate mammal (*Anchipiddus riparius*) have also been found in the vicinity (Miller, 1955).

Age -- Shark River Formation, Lower Eocene (Wilcox), Tertiary.

58. Jericho, Cumberland County, New Jersey

Lithology -- Chocolate brown clay with shell fragments.

Fossils -- This town used to be known as Marlboro because of the fossiliferous clay that was extensively dug here for fertilizer. The last excavations, closed in 1918, can still be seen on the Shepherd Farm; these exposures have long been grown over. The "Shiloh Marl," as it was then called, yielded a diverse fauna of Miocene marine animals when the pits were in operation. Today a few fossils may be found in surrounding fields, gullies, and stream valleys. Fragments of the mollusks *Isognomon, Astarte, Eucrassatella, Mercenaria,* and *Turritella* are still found in eroded areas. The old pits also produced large shark teeth (*Carcharodon, Isaurus*) and cetacean material. This fauna is related to the Middle Miocene Chesapeake Group of Maryland; specifically, Gernant *et al.* (1971) correlate this deposit with the Calvert Formation, exposed in the Calvert Cliffs along the western shore of Chesapeake Bay. Apparently the marl at this site was deposited as part of the Miocene transgression that created an embayment stretching from North Carolina up into New Jersey. Deposition took place in shallow nearshore to mid-shelf environments. Whitmore (*in* Gernant *et al.*, 1971) has suggested that the Miocene embayment was a calving ground for primitive baleen whales; sharks came in to prey on the cetaceans.

Age -- Alloway Clay Member (= "Shiloh Marl"), Kirkwood Formation, Early Middle Miocene (Hemingfordian-Barstovian?), Tertiary.

59. Greenwich, Cumberland County, New Jersey

Lithology -- White granular quartzite with many shells.

Fossils -- The "Cohansey quartzite" can be found in fields behind the historic Harding House in Greenwich. Richards (1956) also reports it from the beds of Cohansey Creek and Mill Creek near Fairton. The light-colored rocks are stained brown by iron in places and contain numerous shell fragments. The shells are petrified, having been replaced by opal and chalcedony (Isphording, 1970) The most common forms in the quartzite are *Crassostrea* and *Turritella*. The presence of oysters and the coarser-grained siliceous nature of the rock suggests a shallower environment of deposition than in the Alloway Clay Member of locality 58. Induration of the original sediment may have been accomplished by percolation of silica-saturated groundwater, precipitating out cementing silica minerals. It is conceivable that this silica-rich water was derived from the nearby superjacent Cohansey Formation, which in many places is an almost pure quartz sand.

Age -- Kirkwood Formation, Early Middle Miocene (Hemingfordian-Barstovian?), Tertiary.

60. Washington Township, Gloucester County, New Jersey

Lithology -- White, yellow, and pink fine quartz sand.

Fossils -- In various excavations, notably sand pits, the Grenloch Sand Member of the Kirkwood Formation is exposed. Several sand pits in Washington Township have yielded specimens of silicified wood. The petrified plant material is generally white to yellow in color, showing wood grain texture on the surface. While it is usually found in smaller fragments, large sections of log size

(two to four feet long) are also known. Other localities where silicified wood has been found include Blackwood, Lindenwold, and Harrisonville. The trees that gave rise to the petrified wood were probably cedar or cypress, types that grow along the coast or along stream valleys near the coast. The Grenloch Sand Member, which interfingers with and overlies the Alloway Clay Member, represents shallowing and regression. The overlying unit, the Cohansey Formation, was probably deposited as the sea shallowed further in a complex of environments including fluvial, deltaic, and marginal marine systems (Isphording & Lodding *in* Subitzky, 1969).

Age -- Grenloch Sand Member, Kirkwood Formation, Early Middle Miocene (Hemingfordian-Barstovian?), Tertiary.

QUATERNARY PERIOD. It has been customary to divide the Cenozoic into two periods--the Tertiary and Quaternary. The Quaternary consists of the Pleistocene and Holocene (Recent) epochs. The Pleistocene was originally defined on the basis of molluskan fossils by Lyell in the Paris Basin. Since Agassiz and others popularized the concept of the "Ice Age," however, it has been common practice to associate the beginning of the Pleistocene with the onset of widespread glaciation. But Pleistocene glaciation was cyclic in nature and may have involved six or more periods of glaciation, interspersed with warmer interglacial phases. Moreover, the timing of glaciation varied in different parts of the world, so glacial onset seems to be a rather arbitrary method of defining the base of the Pleistocene. In recent years there have been attempts to return to the original biostratigraphic boundary. Currently, the Pleistocene is thought to have begun about 2.5 million years ago. The beginning of the Holocene is usually set at about 11,000 years ago, when the last great ice sheet, the Wisconsin glaciation, began its retreat. Again, this date is variable in different areas of the globe, and regions like Greenland might be said to still be in the Pleistocene by this definition.

Widespread Pleistocene glaciation and the intervening interglacial phases are obviously related to climatic variations. In plate tectonic terms, the present continental configuration may be particularly well-suited to glaciation, with continents either surrounding a pole (as in the northern hemisphere) or positioned over a pole (Antarctica). Plate tectonic restriction of Tethyan equatorial currents and the creation of the Isthmus of Panama may have altered global heat circulation patterns and thus set the stage for the spread of the great ice sheets. But others have suggested that the cyclicity of glacial-interglacial alternation is related to external causes; the most famous of these theories is the Milankovitch hypothesis, which posits that cyclically varying changes in the earth's orbital parameters and inclination to the ecliptic are responsible for changes in insolation, climatic variation, and glaciation. Another hypothesis that has stimulated much research is the Antarctic ice surge concept. The phenomenon of glacial surging, when a glacier suddenly accelerates its rate of advance, is well-documented but not thoroughly understood. Extrapolating this phenomenon to the East Antarctic ice sheet, it has been proposed that if this great mass of ice suddenly surged into the ocean the albedo (reflectivity) of the earth would rapidly increase, causing a lowering of global temperature and the beginning of widespread glaciation.

Concomitant with glacial advance and retreat, the volume of water locked up in ice, particularly in continental ice sheets, has changed. This has led to major variations in the volume of water in the world's oceans and corresponding rise and fall of global sea level. During glacial maxima, sea level may have fallen by as much as 150 meters, thus exposing much of the now-submerged areas of continental shelf. There is also evidence that sea level was higher than at present during one or more interglacial phases.

Evidence for lower sea level is frequently brought up by clammers dredging the continental shelf offthe coast of New Jersey. Specimens of mastodon, mammoth, musk-ox, and walrus have been dredged up (Parris, 1983; Whitmore *et al.*, 1967), sometimes from depths of over 200 feet. Streambed localities such as Big Brook (locality 43) have yielded Pleistocene mammal material including giant ground sloth, giant beaver, elk-moose, and reindeer (Parris, 1983). Excavations in various parts of New Jersey have turned up giant ground sloth remains (Richards, 1951) and mastodon skeletons (Jepsen, 1964); many years ago a fossil horse tooth was found in association with fresh-water clams (unionids) in a pit at Fishhouse (now Pennsauken), N.J. Parris (1983) has aptly described the vertebrate fauna and discussed the problems involved in collecting Pleistocene vertebrates in New Jersey.

The principal evolutionary development during the Quaternary was the rise to planetary dominance of the hominids. Some authors (Martin, 1973) have related the migration of man into North America to the extinction of typical Pleistocene forms such as mastodons, mammoths, and ground sloths.

61. Port Kennedy Cave, Valley Forge, Chester County, Pennsylvania

Lithology--Cave deposit in Cambrian Ledger Dolomite.

Fossils--The Port Kennedy Cave yielded one of the best Pleistocene assemblages in the Northeast. Unfortunately, the cave is inaccessible today; it was filled in some years ago in preparation for a national Boy Scout Jamboree at Valley Forge Park. The fossils recovered before this present a good picture of Pleistocene terrestrial biota in the area. Plant remains include pollen, lignified wood, and some perfectly preserved conifer cones; all the vegetation found in the cave is represented by groups living in the region today. The fauna is extensive and includes: dung beetles, turtles, turkey, snipe, porcupine, beaver, pika, insectivores, coyote, dog, red fox, gray fox, a possible dire wolf, badger, raccoon, wolverine, mountain lion, lynx, jaguar, a possible cheetah, short-faced bear, black bear, skunk, llamas, tapir, two species of horse, peccary, white-tailed deer, bison, ground sloth, mastodon, rabbit, and saber-tooth cat (Cope, 1899; Richard White, personal communication).

There is an admixture of faunas represented at this locality; some types are more typical of northerly or cooler climates (porcupine, pika, wolverine, lynx), while others represent a southerly influx (jaguar, short-faced bear, llamas, ground sloth). It is probable that the cave deposit accumulated over a span of time that covered glacial and interglacial phases. Savage & Russell (1983) assign the cave fauna an Irvingtonian age, which could encompass several glacial-interglacia climatic cycles.

The cave was probably used as a den by ground sloth, bear, and some of the larger carnivores. Normal, accidental deaths of animals falling into the cave supplemented the assemblage created by predators dragging in prey and by the death of animals living in the cave.

Age -- Irvingtonian Vertebrate Stage, lower Pleistocene, Quaternary (Nebraskan to Illinoisian?)

62. Maurice River, Port Elizabeth, Cumberland County, New Jersey

Lithology -- Brown sandy clay with numerous shells, underlain by a gray massive clay.

Fossils -- Bluffs along the east bank of the Maurice River just north of Manamuskin Creek expose a shellbed approximately three feet thick. The shellbed is dominated by specimens of the oyster *Crassostrea virginica* (Gmelin), although infrequent fragments of the northern quahog *Mercenaria mercenaria* (Linné) are also present. The density of the oysters, the occurrence of double-valved articulated and young individuals indicates that this was probably an oyster reef or "bank"; the oysters and the lithology strongly argue for an estuarine depositional environment. The fossil shells are found eight to ten feet above the mean high tide; they are "dead" in terms of radiocarbon dating (Richards, 1962, 1970). The elevation is probably due to eustatic sea-level changes rather than isostatic rebound, and the shellbed was deposited during a time of higher sea-level, most likely during the Sangamon interglacial phase.

Age -- Cape May Formation, Pleistocene Epoch, Quaternary (Sangamon).

63. Cape May Canal, Cape May County, New Jersey

Lithology -- Gray silty clay, orange-yellow gravel, and fine yellow sand.

Fossils -- Years ago, spoil piles from dredging the canal yielded a diverse marine fauna. The spoil piles on the south bank are largely grown over and only a few shell fragments remain. The mollusks found here include:

Pelecypoda	Gastropoda
Cyclocardia (Venericardia) borealis (Conrad)	*Urosalpinx cinerea* (Say)
Astarte castanea (Say)	*Nassarius vibex* (Say)
Petricola pholadiformis Lamarck	*N. trivittatus* (Say)
	Ilyanassa obsoleta (Say)
	Neptunea stonei (Pilsbry)
	Polinices duplicatus (Say)

In addition, there are *Cliona* borings, encrusting bryozoa, and pieces of sand dollar (*Echinarachnius*?) tests. Some of the mollusks listed above are common in the area today (*P. pholadiformis, U. cinerea, I. obsoleta, P. duplicatus*), while others suggest cooler water temperatures (*C. borealis, A. castanea, N. trivittatus, N. stonei*). Richards (1956) lists other forms found here, including *N. vibex*, which are more typical of warmer waters.

At present, the only fossiliferous exposure available for observation is on the north bank of the canal west of the Route 9 bridge. At low tide a ledge of gray clay is accessible at the water's edge; this contains the brownish iron-stained molds of pelecypods, probably *Spisula* or *Mercenaria*. The bluff above this layer reveals, above the clay, an orange-yellow gravel with cross-bedding, and above that a fine orange-yellow sand with frost-heaving structures at the base. Taken together with the marine fossils dredged from the bottom of the canal, this exposure can be interpreted as a regressive sequence. The marine fauna at the bottom of the canal is overlain by a silty estuarine clay, which is superseded by a beach and/or fluvial gravel, capped by a wind-blown sand with periglacial features. This suggests a lowering of sea-level at the end of the Sangamon interflacial and the onset of glacial conditions at the beginning of the Wisconsin glaciation. Whereas other Pleistocene formations in southern New Jersey (Bridgeton Formation, Pennsauken Formation) are primarily alluvial gravels derived from glacial run-off, the Cape May Formation represents a complex of marine, estuarine, and alluvial-terrestrial environments deposited during the Sangamon and into the Wisconsin (Minard & Rhodehamel *in* Subitzky, 1969; Richards, 1970; Wolfe, 1977).

Age -- Cape May Formation, Late Pleistocene Epoch, Quaternary (Sangamon-Wisconsin).

64. Atlantic Coast Beaches, Ocean, Atlantic, and Cape May Counties, New Jersey

Lithology -- Clean quartz beach sand with infrequent peat exposures.

Fossils -- Many of the darkened shells washed up on the New Jersey beaches are derived from deposits of Pleistocene and early Holocene age. Since the retreat of the Wisconsin ice sheet from northern New Jersey approximately 11,000 years ago, sea level has steadily risen. At the maximum glacial extent, sea level was as much as 420 feet lower than today and the coast may have been as far as eighty miles east of New Jersey's present beaches (Wolfe, 1977). As the ice sheet melted and sea level rose, barrier islands migrated westward over ancient estuarine deposits. Today, in addition to the vertebrate remains mentioned above, clammers dredging the continental shelf routinely bring up blackened clams, oysters, and clumps of estuarine peat. Blackened shells and exposures of peat are encountered along the present shoreline. The shells have been given their dark color by reduced iron produced in the anoxic environment of the estuarine muds and peats. One such estuarine peat is exposed in patches at low tide along the beach at Whale Beach, between Strathmere and Sea Isle City in Cape May County. The peat is mostly composed of *Spartina* marsh grass remains. Cinquemani *et al.* (1982) have radiocarbon-dated the basal peat in the salt marsh behind Sea Isle City at 3960 $\pm$ 110 years. The peat exposed at Whale Beach is probably older than this, since it has been overridden by barrier island migration.

Typical Quaternary shells washed up along the strand include blacked remains such as:

Pelecypoda

Aequipecten irradians (Lamarck)
A. gibbus (Linné)
Crassostrea virginica (Gmelin)
Mercenaria mercenaria (Linné)
Anomia simplex d'Orbigny
Cyclodardia borealis (Conrad)
Anadara tranversa (Say)

Gastropoda

Crepidula fornicata (Linné)
Busycon carica (Gmelin)
B. canaliculatum (Linné)
Polinices heros (Say)
P. duplicatus (Say)

Additionally, blackened and worn sharks' teeth are found on the beaches. These may be Quaternary or older, and include *Carcharodon, Odontaspis, Isaurus, Galeocerdo,* and *Carcharias*.

Age -- Pleistocene (Wisconsin) and Holocene (Flandrian), Quaternary.

Acknowledgements

The host of people who in various ways helped with this work over the years is too large to list by name, so I have selected those whose encouragement, interest, and aid stand out most clearly in my memory. My apologies are extended to any who might feel slighted, if only through my own oversight.

I would like to dedicate this work to my mother, Mrs. Dorothy Gallagher, who at an early age encouraged my interest in things scientific, and who has continued to offer me support and motivation, particularly during the difficult passages of my life.

Much of this work was done under the auspices of the Academy of Natural Sciences of Philadelphia. I am particularly indebted to Dr. Horace G. Richards, Curator Emeritus, for making the resources of the Academy available to me, and for his help and support over the years. I am also grateful to Dr. Earl A. Shapiro, formerly of the Academy, for his constant encouragement and aid, and specifically for soliciting this paper during his tenure as the first editor of *The Mosasaur*.

I would like to thank those reviewers who read all or part of the manuscript and offered their helpful suggestions: Dr. Donald Baird, Mrs. Carol Faul, Dr. Hermann Pfefferkorn, Kirk Johnson, and William Altimari.

I wish to express my appreciation to those individuals who helped me with specific locality information. These include: Wayne Ferren, Ralph Johnson, Richard White, Michael Bernstein, Leo Hickey, Don Baird, Dave Parris, Earle Spamer, and Don Clements.

Finally, I acknowledge my indebtedness to those many members of the Delaware Valley Paleontological Society who have shared their excitement and enthusiasm with me as they displayed their latest "finds."

References Cited

ABBOTT, R. Tucker. 1968. *Seashells of North America.* New York: Golden Press, 280 pp.

ALVAREZ, Luis W., Walter ALVAREZ, Frank ASARO, & Helen V. MICHEL. 1980. Extraterrestrial cause for the Cretaceous-Tertiary extinction. *Science,* 208:1095-1108.

ALVAREZ, Walter, Erle G. KAUFFMAN, Finn SURLYK, Luis W. ALVAREZ, & Helen V. MICHEL. 1984. Impact theory of mass extinctions and the invertebrate fossil record. *Science,* 223:1135-1141.

ARCHIBALD, J. D., & W. A. CLEMENS. 1982. Late Cretaceous extinctions. *Am. Scientist,* 70:377-385.

BAIRD, D. 1964. *A fossil sea turtle from New Jersey.* New Jersey State Museum Investigations, no. 1, 26 pp.

————. 1966. What's new in the Cretaceous. *Delware Valley Earth Sciences Soc. News Bull.,* 3(4)(Oct.):81-85.

————. 1967. Age of fossil birds from the greensands of New Jersey. *The Auk,* 84:260-262.

BAIRD, Donald, & John R. HORNER. 1977. A fresh look at the dinosaurs of New Jersey and Delaware. *New Jersey Acad. Sciences Bull.,* 22:50.

BAIRD, D., & Peter M. GALTON. 1981. Pterosaur bones from the Upper Cretaceous of Delaware. *Jour. Vertebrate Paleontology,* 1(1):67-71.

BERRY, Edward. 1911. *The flora of the Raritan Formation.* New Jersey Geol. Survey Bull. 3, 233 pp.

BOYER, Paul S., *et al.* 1974. Greensand fecal pellets from New Jersey. Geol. Soc. America, Northeast Sect., Ann. Meeting, *Abstracts with Programs,* 6(1):6-7.

CANU, F., & R. S. BASSLER. 1933. *The bryozoan fauna of the Vincentown Limesand.* U.S. Natl. Mus. Bull. 165, 108 pp.

CHAFEE, Robert G. 1939. A New Jersey mosasaur of the subfamily Platecarpinae. *Notulae Naturae* (Acad. Natural Sciences Philadelphia), no. 37, 5 pp.

CINQUEMANI, Leonard J., Walter S. NEWMAN, J. A. SPERLING, L. F. MARCUS, & R. R. PANDI. 1982. Holocene sea level changes and vertical movements along the East Coast of the United States: A preliminary report. *In: Holocene sea level fluctuations, magnitude and causes.* INQUA, Univ. South Carolina, Columbia.

COBBAN, W. A. 1974. *Ammonites from the Navesink Formation at Atlantic Highlands, New Jersey.* U.S. Geol. Survey Prof. Paper 845, 21 pp.

COLBERT, Edwin H. 1948. A hadrosaurian dinosaur from New Jersey. *Acad. Natural Sciences Philadelphia Proc.,* 100: 23-37.

COOKE, C. Wythe, & L. W. STEPHENSON. 1928. The Eocene age of the supposed late Upper Cretaceous greensand marls of New Jersey. *Jour. Geology,* 36:139-148.

COPE, E. D. 1899. Vertebrate remains from the Port Kennedy bone deposit. *Acad. Natural Sciences Philadelphia Jour.,* 2:193-267.

DORF, Erling (ed.). 1957. *Guidebook for field trips, Atlantic City meeting, 1957.* New York: Geol. Soc. America.

DOYLE, James A., & Leo J. HICKEY. 1976. Pollen and leaves from the mid-Cretaceous Potomac Group and their bearing on early angiosperm evolution. *In:* Charles B. Beck, ed., *Origin and early evolution of angiosperms.* New York: Columbia University Press, 341 pp.

FELDMAN, Howard R. 1977. Paleoecology and morphologic variation of a Paleocene terebratulid brachiopod (*Oleneothyris harlani*) from the Hornerstown Formation of New Jersey. *Jour. Paleontology,* 51:86-107.

FORSTER, Catherine A. 1984. The paleoecology of the ornithopod dinosaur *Tenontosaurus tilletti* from the Cloverly Formation, Big Horn Basin of Wyoming and Montana. *The Mosasaur,* 2:151-163 (this issue).

FOX, S. K., & R. K. OLSSON. 1960. *Guidebook for first annual conference.* Atlantic Coastal Plain Geological Conference, October 8-9, 1960.

GALLAGHER, William B. 1974. *Guide to fossil localities for New Jersey earth science teachers.* Master's thesis, Glassboro State College, Glassboro, New Jersey.

————. 1982. Hadrosaurian dinosaurs from Delaware. *Delaware Valley Paleontol. Soc. Newsletter,* 4(10):3-4.

GERNANT, Robert E., Thomas G. GIBSON, & Frank C. WHITMORE, Jr. 1971. *Environmental history of the Maryland Miocene.* Baltimore: Maryland Geol. Survey.

GILL, H., L. A. SIRKIN, & J. A. DOYLE. 1969. Cretaceous deltas in the New Jersey Coastal Plain. *Geol. Soc. America Abs. with Programs,* pt. 7, p. 79.

GOSNER, Kenneth L. 1978. *A field guide to the Atlantic seashore.* Boston: Houghton Mifflin Co., 329 pp.

GREACEN, Katherine Fielding. 1941. *The stratigraphy, fauna and correlation of the Vincentown Formation.* New Jersey Bureau of Geology and Topography.

GROOT, J., D. ORGANIST, & H. G. RICHARDS. 1954. *Marine Upper Cretaceous formations of the Chesapeake and Delaware Canal.* Delaware Geol. Survey Bull. 3.

HECKER, R. F. 1957. *Introduction to paleoecology.* New York: American Elsevier Publishing Co.

HICKEY, Leo J. 1977. Changes in angiosperm flora across the Cretaceous-Paleocene boundary. *Jour. Paleontology,* 51(2, Suppl., pt. 3):14-15 [abs.].

————. 1981. Land plant evidence compatible with gradual, not catastrophic, change at the end of the Cretaceous. *Nature,* 292:529-531.

HICKEY, Leo J., & James A. DOYLE. 1977. Early Cretaceous fossil evidence for angiosperm evolution. *Botanical Review,* 43(1):3-104.

HICKEY, L. J., R. M. WEST, M. R. DAWSON, & D. K. CHOI. 1983. Arctic terrestrial biota: Paleomagnetic evidence of age disparity with mid-northern latitudes during the Late Cretaceous. *Science,* 221:1153-1156.

HORNER, John R. 1979. Upper Cretaceous dinosaurs from the Bearpaw Shale (marine) of south-central Montana with a checklist of Upper Cretaceous dinosaur remains from marine sediments in North America. *Jour. Paleontology,* 53(3):566-577.

ISPHORDING, W. C. 1970. Petrology, stratigraphy, and redefinition of the Kirkwood Formation (Miocene) of New Jersey. *Jour. Sedimentary Petrology*, 40(3):986-997.

JEPSEN, Glenn L. 1964. *A New Jersey mastodon*. New Jersey State Museum Bull. 6.

JORDAN, Robert R. 1983. *Stratigraphic nomenclature of nonmarine Cretaceous rocks of inner margin of coastal plain in Delaware and adjacent states*. Delaware Geol. Survey, Rept. of Investigations, no. 37, 43 pp.

KOCH, Robert C., & Richard K. OLSSON. 1974. Microfossil biostratigraphy of the uppermost Cretaceous beds of New Jersey. *Geol. Soc. America Abs. with Programs*, 6:45-46.

———. 1977. Dinoflagellate and planktonic foraminiferal biostratigraphy of the uppermost Cretaceous of New Jersey. *Jour. Paleontology*, 51:480-491.

KRAUSE, D., & D. BAIRD. 1979. Late Cretaceous mammals east of the North American Western Interior Seaway. *Jour. Paleontology*, 53:562-565.

KRINSLEY, O., & M. SCHENCK. 1964. The paleoecology of a transition zone across an Upper Cretaceous boundary in New Jersey. *Paleontology*, 7, pt. 2, pp. 266-280.

LaBARBERA, M. 1981. The ecology of Mesozoic *Gryphaea*, *Exogyra*, *Ilymatogyra* (Bivalvia: Mollusca) in a modern ocean. *Paleobiology*, 7:510-526.

LAUGINIGER, Edward M. 1984. An upper Campanian vertebrate fauna from the Chesapeake and Delaware Canal, Delaware. *The Mosasaur*, 2:141-149 (this issue).

LAUGINIGER, Edward M., & Eugene F. HARTSTEIN. 1981. *Delaware fossils*. Wilmington: Delaware Mineralogical Soc.

———. 1983. *A guide to fossil sharks, skates, and rays from the Chesapeake and Delaware Canal area, Delaware*. Delaware Geol. Survey, open file rept. 21, 64 pp.

LEIDY, J. 1858. Remarks concerning *Hadrosaurus*. *Acad. Natural Sciences Philadelphia Proc.*, 10:213-219.

LEWIS, J. Volney, & Henry B. KÜMMEL. 1940. *The geology of New Jersey*. New Jersey Dept. Conservation and Development.

MARTIN, P. S. 1973. The discovery of America. *Science*, 179:969-974.

McLENNAN, Jeanne D. 1973. *Dinosaurs in Maryland*. Maryland Geol. Survey.

MILLER, Halsey W. 1955. A checklist of the Cretaceous and Tertiary vertebrates of New Jersey. *Jour. Paleontology*, 4:910-912.

———. 1956. Paleocene and Eocene and Cretaceous-Paleocene boundary in New Jersey. *Am. Assoc. Petroleum Geologists Bull.*, 40(4):722-736.

MINARD, James P., & James P. OWENS. *Pre-Quaternary geology of the New Egypt quadrangle, New Jersey*. U.S. Geol. Survey.

MINARD, James P., *et al.* 1969. *Cretaceous-Tertiary boundary in New Jersey, Delaware, and eastern Maryland*. U.S. Geol. Survey Bull. 1274-H.

OFFICER, C. B., & C. L. DRAKE. 1983. The Cretaceous-Tertiary transition. *Science*, 219:1383-1390.

OLSON, Storrs, & David C. PARRIS. In press. Cretaceous birds from the Hornerstown Formation of New Jersey.

OLSSON, Richard K. 1963. Latest Cretaceous and earliest Tertiary stratigraphy of New Jersey coastal plain. *Am. Assoc. Petroleum Geologists Bull.*, 47(4):643-665.

ORTH, Charles J., James S. GILMORE, Jere D. KNIGHT, Charles L. PILLMORE, & Robert H. TSCHUDY. 1981. An iridium abundance anomaly at the palynological Cretaceous-Tertiary boundary in northern New Mexico. *Science*, 214: 1341-1343.

OSBORN, Henry Fairfield. 1931. *Cope: master naturalist*. Princeton, N.J.: Princeton University Press, 740 pp.

OWENS, James P., & James P. MINARD. 1960. *The geology of the north-central part of the New Jersey Coastal Plain*. Baltimore: Johns Hopkins University.

OWENS, James P., & Norman F. SOHL. 1969. Shelf and deltaic paleoenvironments in the Cretaceous-Tertiary formations of the New Jersey Coastal Plain. *In:* Seymour Subitzky (ed.), *Geology of selected areas in New Jersey and Pennsylvania*. New Brunswick, N.J.: Rutgers Univ. Press, 382 pp.

———. 1973. Glauconites from New Jersey-Maryland Coastal Plain: their K-Ar ages and application in stratigraphic studies. *Geol. Soc. America Bull.*, 84:2811-2838.

OWENS, James P., James P. MINARD, Norman F. SOHL, & James F. MELLO. 1970. *Stratigraphy of the outcropping post-Magothy Upper Cretaceous formations in southern New Jersey and northern Delmarva Peninsula, Delaware and Maryland*. U.S. Geol. Survey Prof. Paper 674, 60 pp.

PARRIS, David C. 1974. Additional records of plesiosaurs from the Cretaceous of New Jersey. *Jour. Paleontology*, 48(1):32-35.

———. 1983. New and revised records of Pleistocene mammals of New Jersey. *The Mosasaur*, 1:1-21.

PICKETT, Thomas E. 1972. *Guide to common Cretaceous fossils of Delaware*. Delaware Geol. Survey.

PICKETT, T. E., J. C. KRAFT, & K. SMITH. 1971. Cretaceous burrows--Chesapeake and Delaware Canal, Delaware. *Jour. Paleontology*, 45:209-211.

RICHARDS, Horace G. 1943. Fauna of the Raritan Formation of New Jersey. *Acad. Natural Sciences Philadelphia Proc.*, 95:15-32.

———. 1951. *Some recent discoveries of Pleistocene mammals from New Jersey*. New Jersey Dept. Conservation and Economic Development, Bull. 60 (Geol. Ser.), pp. 1-8.

———. 1956. *Geology of the Delaware Valley*. Philadelphia: Mineralogical Society of Pennsylvania.

———. 1962. Studies on the marine Pleistocene. *Am. Philos. Soc. Trans.*, 52, pt. 3.

———. 1970. Changes in shoreline during the last million years. *Am. Philos. Soc. Proc.*, 114:198-204.

RICHARDS, Horace G., & William B. GALLAGHER. 1974. The problem of the Cretaceous-Tertiary boundary in New Jersey. *Notulae Naturae* (Acad. Natural Sciences Philadelphia), no. 449, 6 pp.

RICHARDS, Horace G., & Earl A. SHAPIRO. 1963. *An invertebrate macrofauna from the Upper Cretaceous of Delaware*. Delaware Geol. Survey, Rept. Investigations 7, 37 pp.

RICHARDS, Horace G., *et al.* 1958, 1962. *The Cretaceous fossils of New Jersey: Parts I and II*. New Jersey Bureau of Geology and Topography.

SAVAGE, D. E., & D. E. RUSSELL. 1983. *Mammalian paleofaunas of the world*. Reading, Mass.: Addison-Wesley Pub. Co., 432 pp.

SPANGLER, W. B., & Jahn PETERSON. 1950. Geology of the Atlantic Coastal Plain in New Jersey, Delaware, Maryland and Virginia. *Am. Assoc. Petroleum Geologists Bull.*, 34: 1-99.

SUBITZKY, Seymour (ed.). 1969. *Geology of selected areas in New Jersey and eastern Pennsylvania*. New Brunswick, N.J.: Rutgers University Press.

THAYER, Charles W. 1983. Sediment-mediated biological disturbance and the evolution of marine benthos. *In:* Michael J. S. Tevesz & Peter L. McCall (eds.), *Interactions in Recent and fossil benthic communities*. New York: Plenum Press, pp. 479-625.

THOMPSON, Ida. 1982. *The Audubon Society field guide to North American fossils*. New York: Alfred A. Knopf, 846 pp.

VALENTINE, James W. 1973. *Evolutionary paleoecology of the marine biosphere*. Englewood Cliffs, N.J.: Prentice-Hall, Inc.

VALENTINE, J. W., & E. M. MOORES. 1970. Plate-tectonic regulation of faunal diversity and sealevel: a model. *Nature*, 228:657-659.

WELLER, Stuart. 1907. *A report on the Cretaceous paleontology of New Jersey*. New Jersey Geol. Survey, Paleontology Ser., Vol. 4.

WIDMER, Kemble. 1964. *The geology and geography of New Jersey*. Princeton: D. Van Nostrand Co.

WHITE, R. S., Jr. 1972. A recently collected specimen of *Adocus* (Testudines: Dermatemydidae) from New Jersey. *Notulae Naturae* (Acad. Natural Sciences Philadelphia), no. 447, 10 pp.

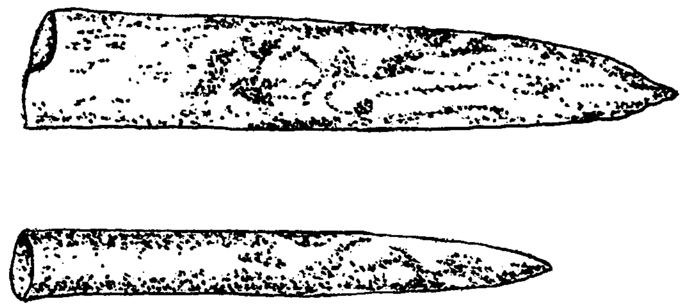
WHITMORE, F. C., Jr., K. O. EMERY, H. B. S. COOKE, & D. J. P. SWIFT. 1967. Elephant teeth from the Atlantic continental shelf. *Science*, 156:1477-1481.

WOLFE, Peter E. 1977. *The geology and landscapes of New Jersey*. New York: Crane, Russak and Co., 351 pp.

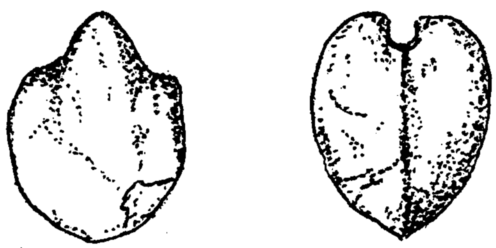
Plates I - IV

Typical Cretaceous and Cenozoic
Fossils of the Delaware Valley

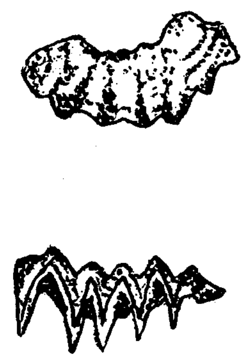
(All specimens X1)



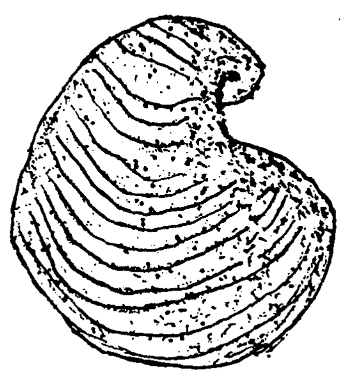
Belemnitella americana



Cardium tenuistriatum

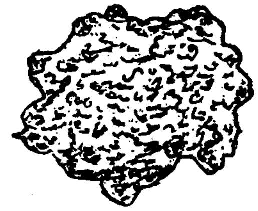


Agerostrea falcata



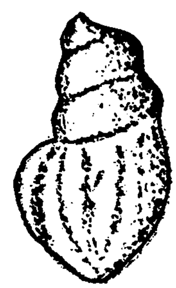
Exogyra cancellata

Choristothyris plicata



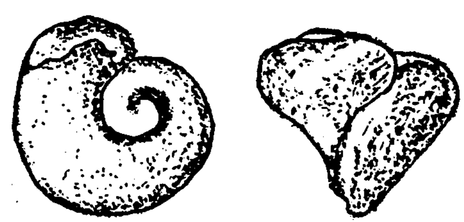
Cliona cretacica

Gyrodes abyssinus

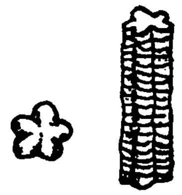


Anchura pennata

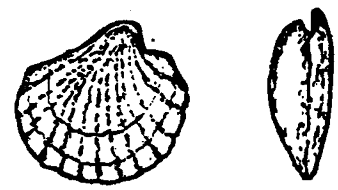
Turritella encrinoides



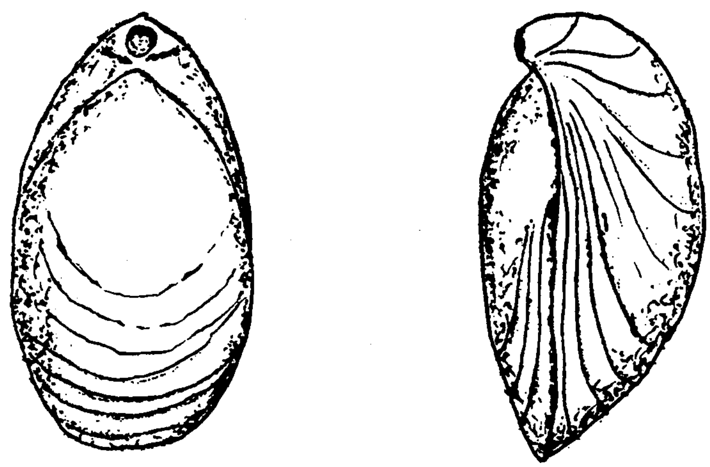
Pyropsis trochiformis



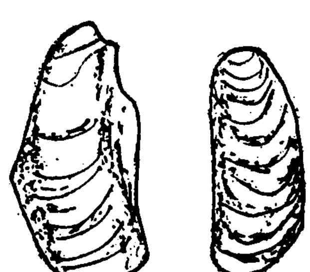
Pentacrinus bryani



Venericardia antiquata

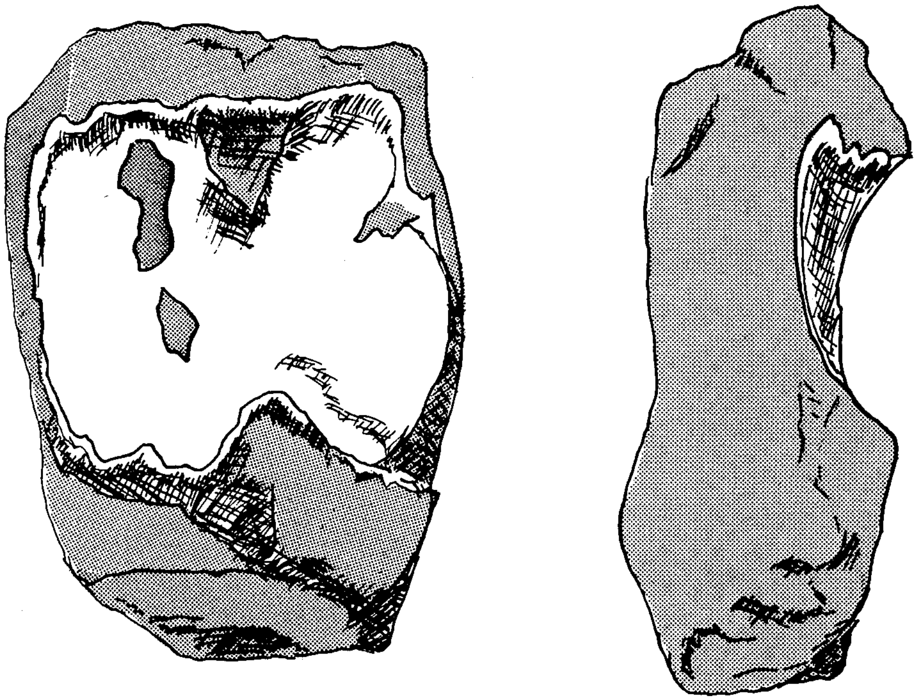


Oleneothyris harlani



Gryphaeostrea vomer

Etea delawarensis



Vertebra Fragment

Tooth

HADROSAUR INDETERMINATE

From Gallagher (1982)

IN MEMORIAM:
EDWIN D. McKEE

The introduction to the following paper opens with an anecdote from the experiences of Edwin D. McKee. This is appropriate because no geologist could call the Grand Canyon "his" more than Dr. McKee could. "Eddie" died on July 23, 1984, after a brief illness; he was 77. He had studied the Grand Canyon for more than 50 years, but during his widely traveled professional career he also became a world-renowned sedimentologist and stratigrapher.

Word of Eddie's passing was sent to me by a long-time friend of his, who has lived and worked at Grand Canyon for more than 25 years. She wrote: "My own feelings of great personal loss of a dear friend are mixed with regret that he could not have the pleasure of completing some of the tasks he still hoped to achieve and were so dear to his heart. True, his geologic work will be carried on by others, but few can hope to bring to it the intense dedication and the long acquaintance with the Canyon that uniquely suited him for the work."

Eddie's interest in the Grand Canyon went far beyond geology, however. Over the years he had also written on biology, archaeology, history, and the Native Americans of the Grand Canyon area. He was a friend to residents of the area and to professional acquaintances the world over. He was a prolific writer; his works that deal in whole or in part with the Grand Canyon number nearly 200. Eddie had the distinct honor of being the most-published single author on the Grand Canyon and the Colorado River. But his accomplishments and interests went far abroad, too. Even until shortly before his death, Eddie traveled around the world to study what appear to be modern analogs of fossil depositional environments. The applications of his many pioneering studies are now incorporated among the principal themas of sedimentology and stratigraphy.

Eddie's long career never took him far from the Grand Canyon. As Park Naturalist at Grand Canyon National Park from 1929 to 1941, he instituted several still-existing programs and developed the fine study collections. After 1941, Eddie became assistant director of the Museum of Northern Arizona, in Flagstaff, and later became a member of the museum's Board of Trustees, his last 10 years as Emeritus Trustee. He was chairman of the Department of Geology at the University of Arizona, in Tucson, before joining the U.S. Geological Survey. He eventually went to the USGS facilities in Denver, Colorado, where he continued his research, even after retirement, until his death. Yet, despite his diversified research interests, Eddie kept turning again to the Grand Canyon--turning to a mentor, turning to the answers in the back of the book.

Eddie McKee's life-long devotion to interpreting and understanding the Grand Canyon is without parallel. Continuing his work will be a herculean task, but one made easier thanks to the amazingly strong foundation that Eddie built in his publications and records. It seems appropriate, then, to dedicate this paper to the memory of Eddie McKee. I make this dedication with both profound sorrow and heartfelt appreciation.

E.E.S.